Overview of Proposal:

High Resolution Climate Model Simulations of Recent Hurricane and Typhoon Activity: The Impact of SSTs and the Madden Julian Oscillation

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Workshop on "High-Resolution Climate Modeling”
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Trieste, Italy

Overview

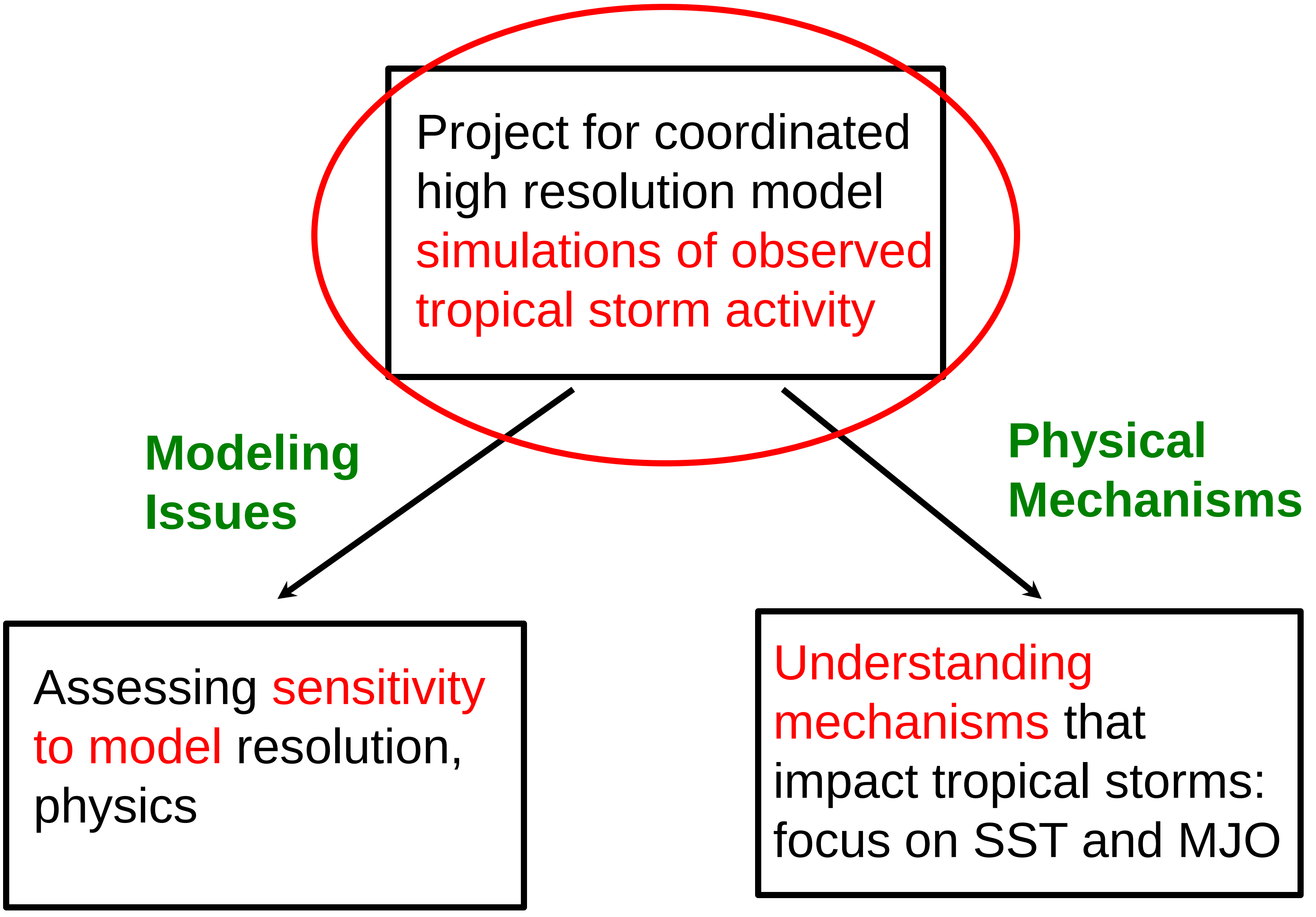
Project for coordinated high resolution model simulations of observed tropical storm activity

Modeling Issues

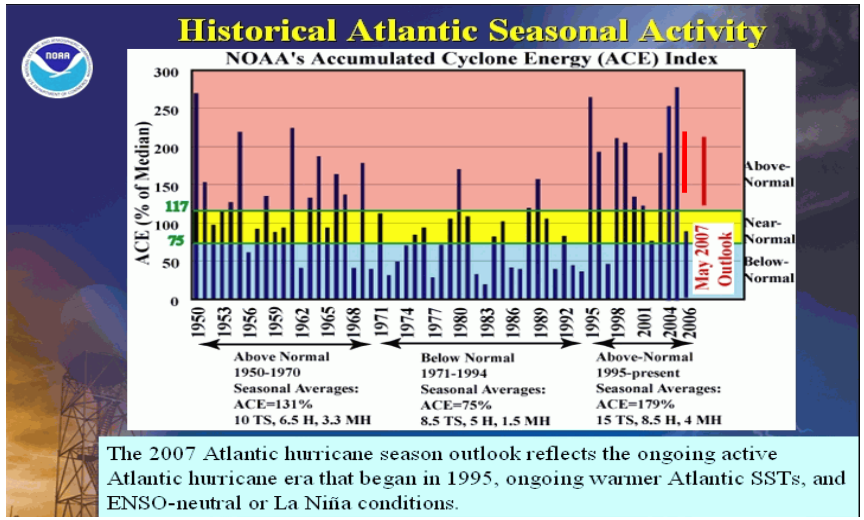
Assessing sensitivity to model resolution, physics

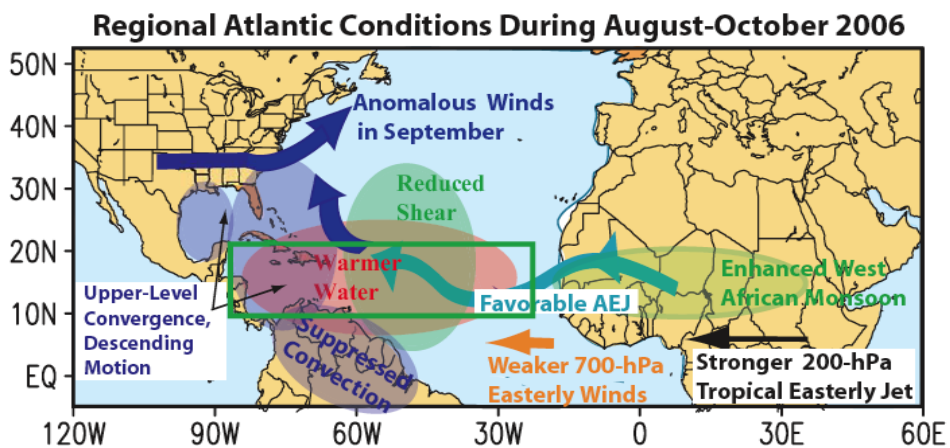
Physical Mechanisms

Understanding mechanisms that impact tropical storms: focus on SST and MJO


Project for coordinated high resolution model simulations of observed tropical storm activity
Modeling Issues
Physical Mechanisms
Assessing sensitivity to model resolution, physics
Understanding mechanisms that impact tropical storms: focus on SST and MJO

Improve our understanding and simulation of the links between tropical storms and sub-seasonal to decadal variability





Project Overview

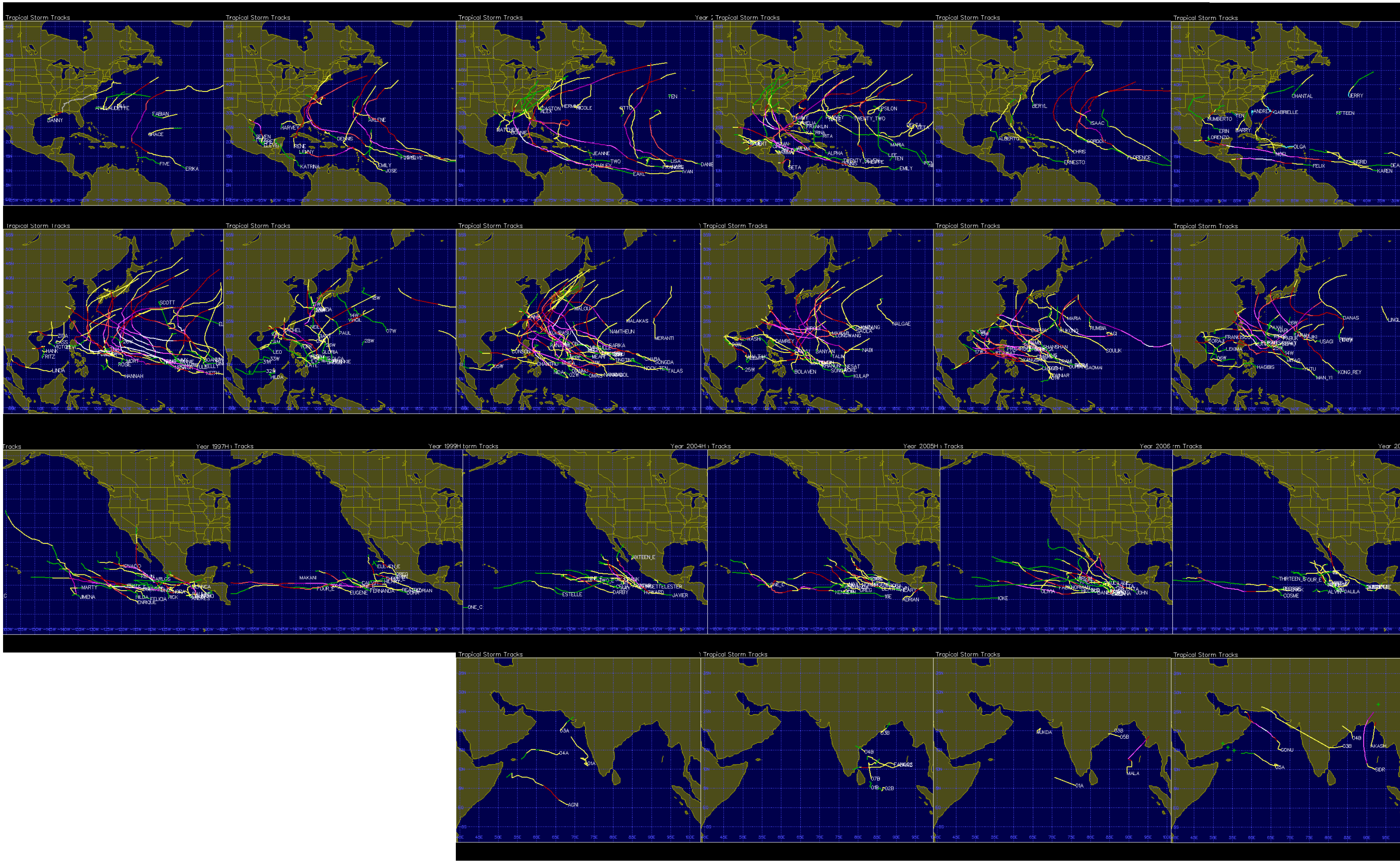
- **Description:** A coordinated international project to carry out and analyze high-resolution (and companion coarser resolution) climate simulations of tropical storm activity with a number of state-of-the-art global climate models (*targeting 20-100km horizontal resolution*)
- **Issues to be addressed:** The mechanisms by which **SST**s control tropical storm activity on seasonal to inter-annual and longer time scales, the modulation of that activity by the **Madden Julian Oscillation** on sub-seasonal time scales, and the sensitivity to **model physics and resolution**.
- **Approach:**
  - Simulate selected years/seasons including some with highly unusual tropical storm activity (AMIP and coupled)
  - Address physical mechanisms through coordinated experimentation (SST and MJO)
  - Address resolution dependence and impact of physics through coordinated experimentation
  - Develop/decide on common set of metrics for evaluation/validation
- **Sponsorship:** endorsed by CLIVAR (AAMP) in April 2007

SST Experiments

- *Table 1: Summary of proposed simulation experiments with specified or predicted SSTs: With the exception of the experiments in the last row, the model resolution should be at the equivalent of 1 degree or better. Encourage an ensemble of about 5. The source of the specified SST fields are left to each organization, but we would encourage the use of the latest HADISST or latest Reynolds products. The AGCM runs could alternatively be done with an anomaly mixed layer ocean. Additional runs with a high-resolution fully coupled model initialized in April of each year are also encouraged. Participation using high resolution regional models is also of interest, especially if it allows assessing the impact of downscaling a global model simulation.* ***Added 2006 and 2007****: had less than expected storm activity – include runs* ***to assess aerosol impact****. *end of April starts make them more useful to CPC's seasonal outlooks.*

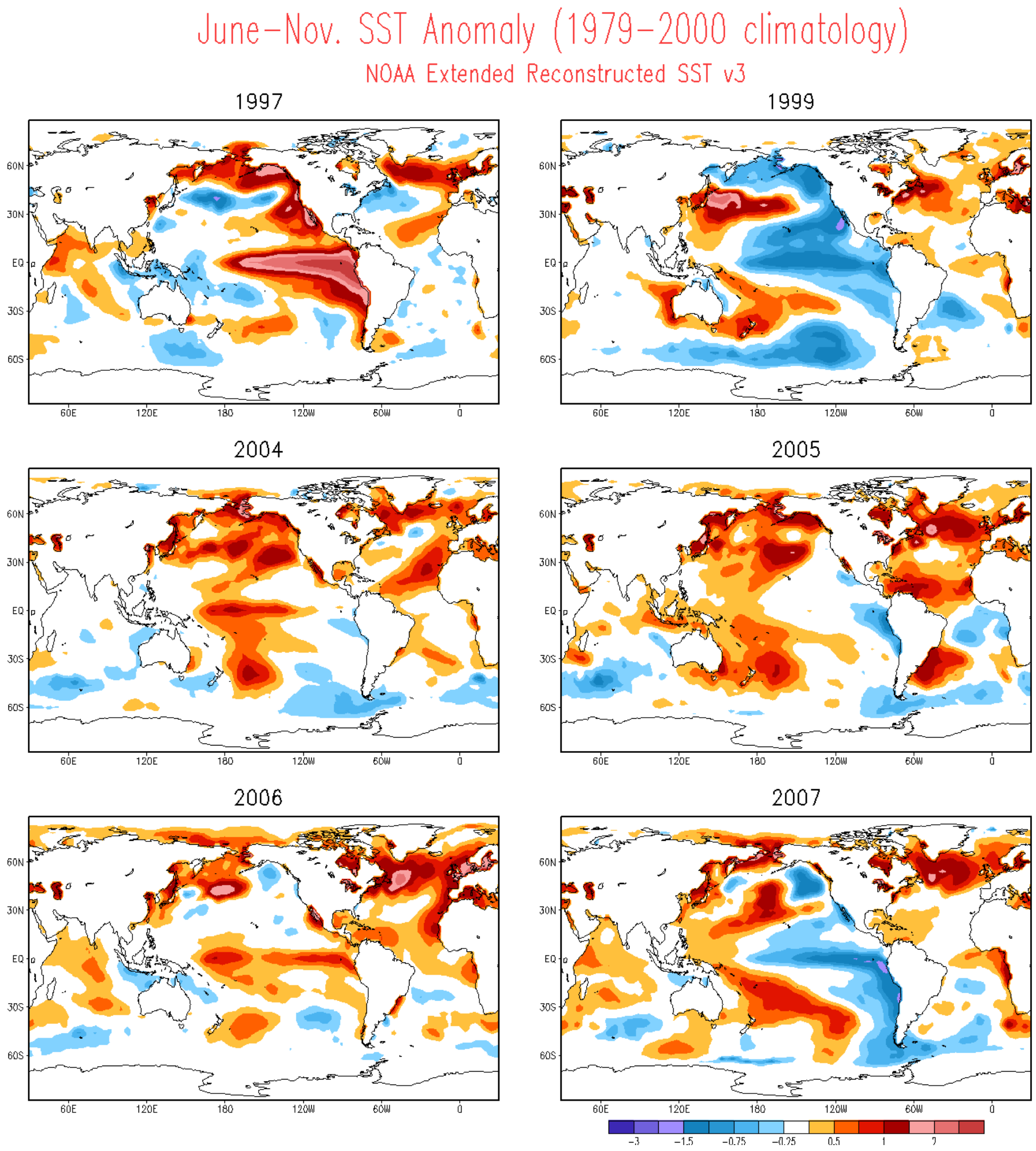
SST	**Period (Ensemble of 5 or more)**	**Some Interesting Events**
2005	(April*) May 15- Nov 30	Warm Atlantic, record number of Atlantic hurricanes
2004	(April) May 15- Nov 30	Record 10 tropical cyclones hit Japan, a hurricane formed off the Brazilian coast, Frances, Ivan and Jeanne devastated parts of Florida and the Caribbean during September.
1999	(April) May 15- Nov 30	La Nina conditions, 2 major Indian Ocean Cyclones, reduced number of west Pacific typhoons
1997	(April) May15 – Nov 30	El Nino conditions, reduced number of Atlantic hurricanes, three of the strongest typhoons on record occurred in the Pacific
Climatology (SST averaged for 1979-2005)	(April) May 15- Nov 30	Establish baseline tropical storm activity
1950 (1979 min)-present AMIP runs at coarse (~2°) climate model resolution	continuous runs	Establish changes in large-scale environment of tropical storms related to SST changes

1997 1999 2004 2005 2006 2007



Atlantic, West Pacific, East Pacific and Northern Indian Ocean storm tracks for 1997, 1999, 2004, 2005. 2006, 2007. **Green: tropical depression, yellow: tropical storm, red/violet:hurricane/typhoon**. http://weather.unisys.com/hurricane/index.html

SST anomalies for selected years based on a 1979-2000 climatology

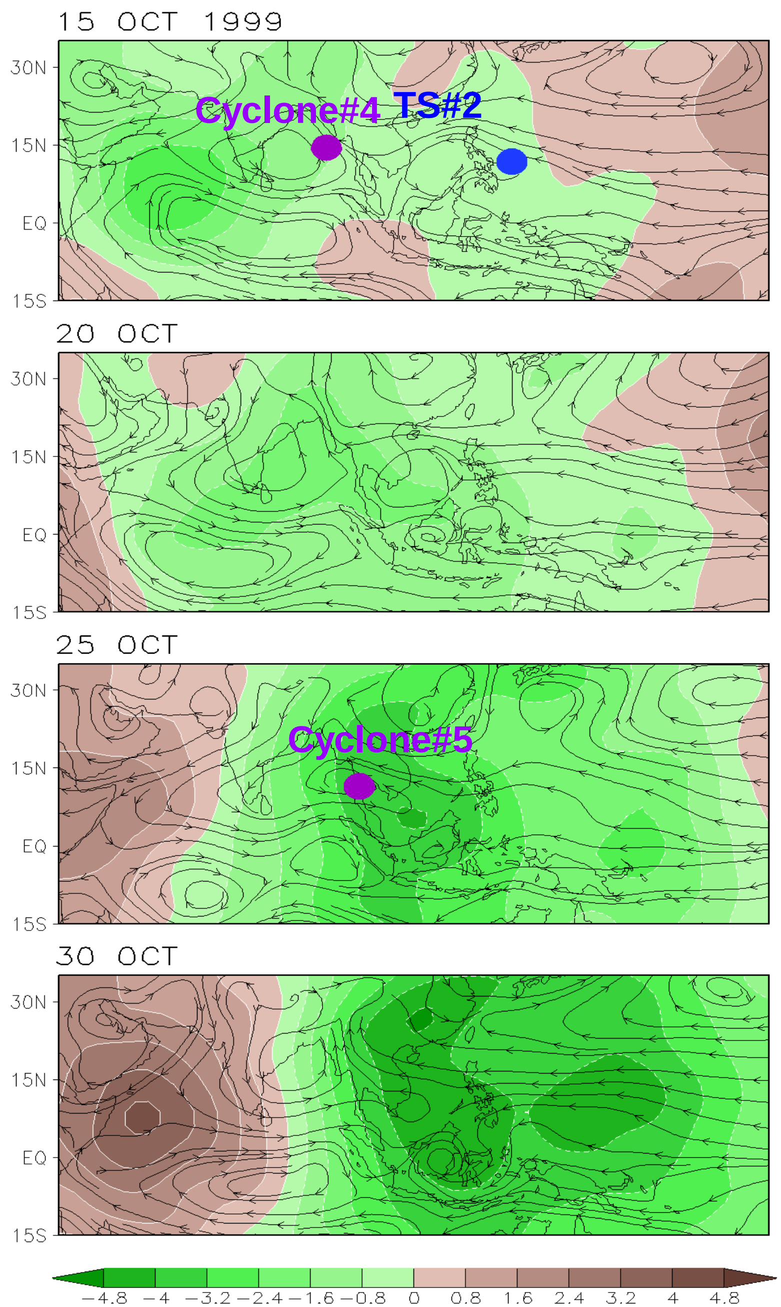


MJO/ISO Experiments

- *Table 2: Summary of proposed forecast experiments to assess impact of MJO. Model resolution should be at the equivalent of 1 degree or higher. The SSTs are either specified or predicted. The atmosphere, and for coupled runs, the ocean, is initialized at different phases of the MJO. Multiple ensemble members (say 5) are highly encouraged, including those to assess the impact of model formulation on the simulation of the MJO.*

Event	**Initial Conditions**	**Potential Impacts of MJO/ISO**
1999 – Two major (cat 4 and 5) cyclones in Bay of Bengal	Oct 5, 15, 20, 25	Predilection for major cyclones in Bay of Bengal
2004 - cluster of typhoons and hurricanes (late July through early September	July 11, 22, Aug 1, 11, 21, 31	Predilection for typhoons and hurricanes especially in east Pacific

VP 200hPa (filtered) & 850hPa Streamline



Location of tropical storm genesis for the two major Cyclones that developed in the Bay of Bengal (#4 and #5) in Oct 1999.

The panels show the pentad averages of the 850mb streamlines and 200mb χ anomalies. Note that the storms form within what appears to be the Rossby Wave response (cyclonic couplets straddling the equator) to the MJO/ISO heating.

Tropical cyclone simulation in high resolution (25km mesh) SNUAGCM

Prepared by Sung-Bin Park

Simulation design

- ✓ Resolution
  - ✓ horizontal : 25km, 0.234375 degree, 1536 X 768 grids
  - ✓ vertical : 21 sigma levels
- ✓ Integration period
  - ✓ 1997(Elino case), 1999(Lanina case), from 14 Apr. to 31 Oct.
  - ✓ 6 ensembles each
- ✓ Output interval :
  - ✓6hourly snapshot

Detection criteria

Based on Bengtsson et al. 1995

	25km	125km	T106[1]
Vorticity	$3.0 \times 10^{-5} s^{-1}$	$3.0 \times 10^{-5} s^{-1}$	$3.0 \times 10^{-5} s^{-1}$
Sea level pressure	$2.1° \times 2.1°$ (2hPa)	$10.1° \times 10.1°$ (2hPa)	$7.9° \times 7.9°$ (-)[2]
Surface wind speed	$5.4° \times 5.4°$ (17 m/s)	$7.9° \times 7.9°$ (12m/s)	$7.9° \times 7.9°$ (15m/s)
Temperature	$2.1° \times 2.1°$ (3℃)	$5.6° \times 5.6°$ (3℃)	$7.9° \times 7.9°$ (3℃)
Duration	3 days	3 days	1.5 days

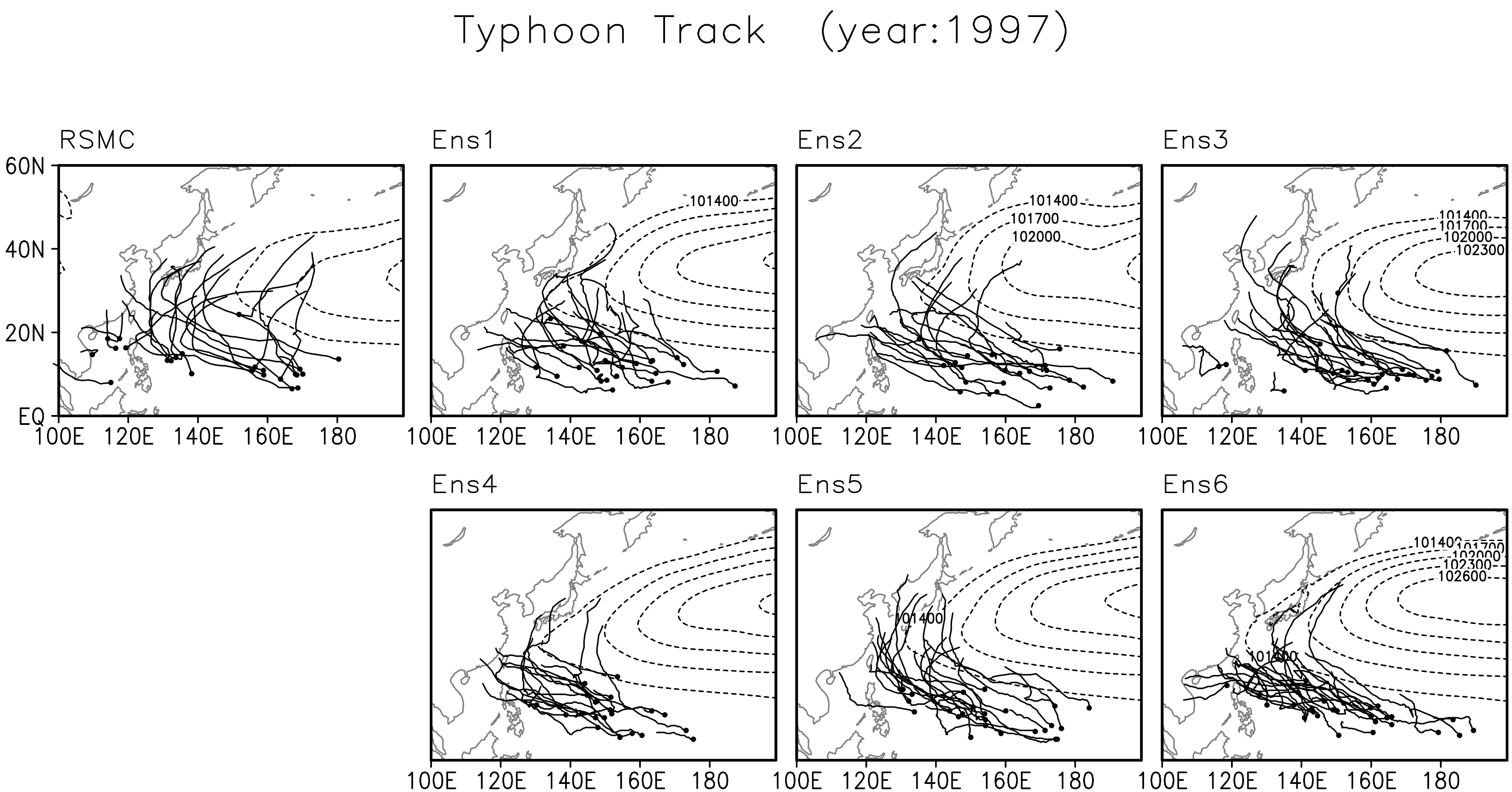
1. Bengtsson et al. (1995)

2. Without specific value of pressure deviation, minimum sea level pressure within a $7.9° \times 7.9°$ area around the point which fulfills vorticity condition.

Overall Statistics

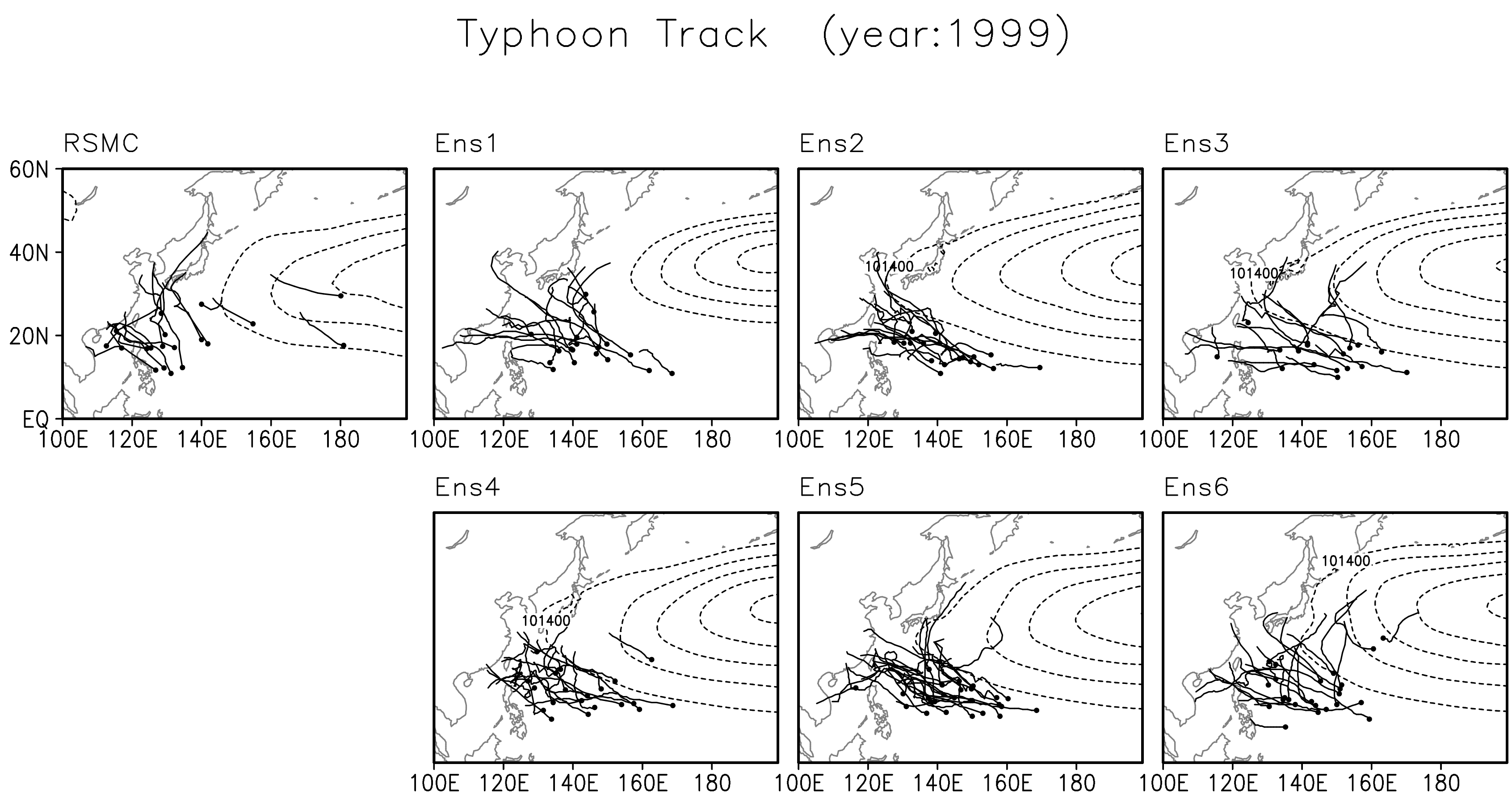
Year	Ensemble	Sea level pressure (hPa)			Wind speed (m/s)		Frequency	Mean lifetime (day)
		Max.	Min.	Mean	Max.	Mean		
1997	1	1009.91	970.72	999.82	45.0	23.1	24	8.7
	2	1009.41	960.55	998.27	57.5	25.7	21	9.9
	3	1011.41	946.44	998.08	62.5	25.6	27	9.1
	4	1009.12	978.37	1000.58	45.4	23.2	22	8.6
	5	1009.02	954.59	999.49	53.1	24.2	24	9.6
	6	1009.74	965.52	1000.39	54.1	23.5	28	10.1
Mean		1009.77	962.70	999.44	52.9	24.2	24.3	9.3
Observation		1000.00	905.00	973.80	56.6	29.9	24	9.8
1999	1	1011.25	958.54	998.76	53.3	24.0	18	7.6
	2	1010.42	961.72	1000.78	50.4	23.2	18	7.5
	3	1010.49	977.52	1001.57	45.7	23.0	17	6.9
	4	1011.89	978.16	1003.29	45.1	21.8	20	7.8
	5	1012.87	974.92	1000.78	46.7	23.3	27	7.4
	6	1010.39	978.24	1001.72	41.1	22.9	24	6.4
Mean		1011.22	971.52	1001.15	47.1	23.0	20.7	7.3
Observation		1010.00	930.00	988.47	46.3	23.1	19	6.9

Tracks



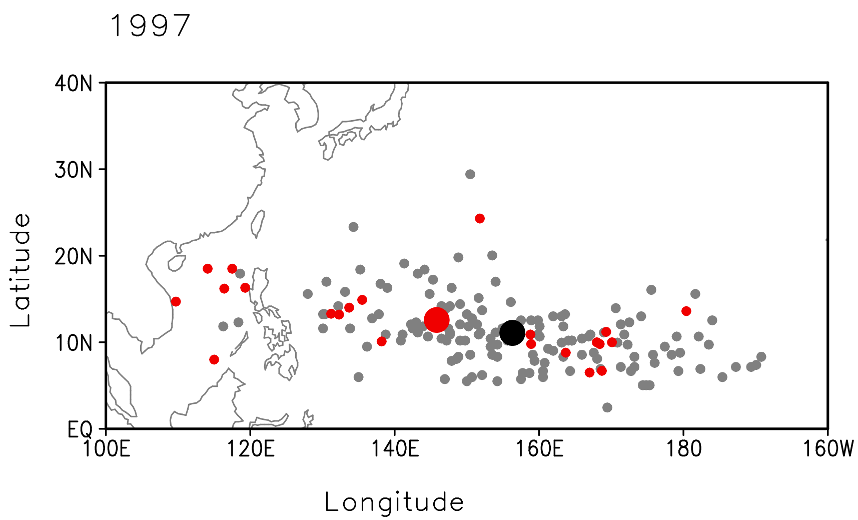
Tracks of observation and simulation (6 ensembles) in 1997 and 1999. The sea level pressure over 1014hPa is contoured, and averaged from May to October.

Tracks



Typhoon Track (year:1999)
RSMC
Ens1
Ens2
Ens3
Ens4
Ens5
Ens6
60N
40N
20N
EQ
100E 120E 140E 160E 180
101400

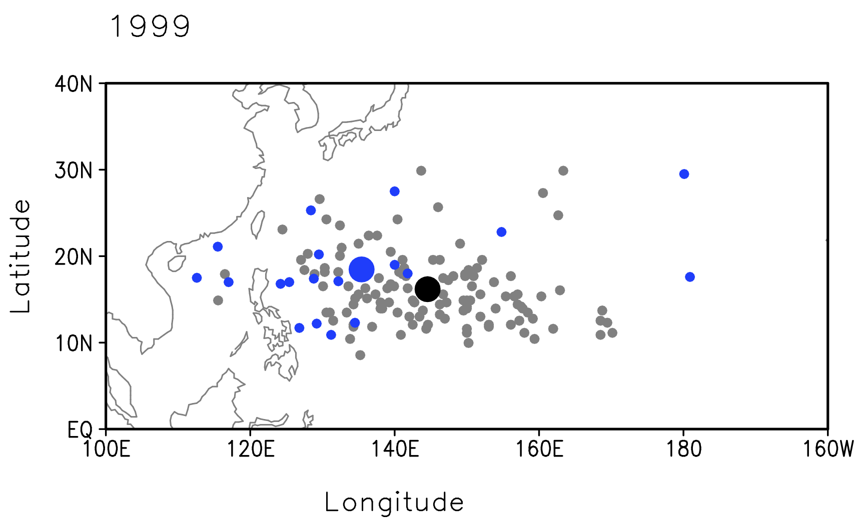
Genesis location



1997 mean location

	model	obs
Mean Lon.:	156.3	145.82
Mean Lat.:	11.08	12.57

Mean location ● : model ● : obs.



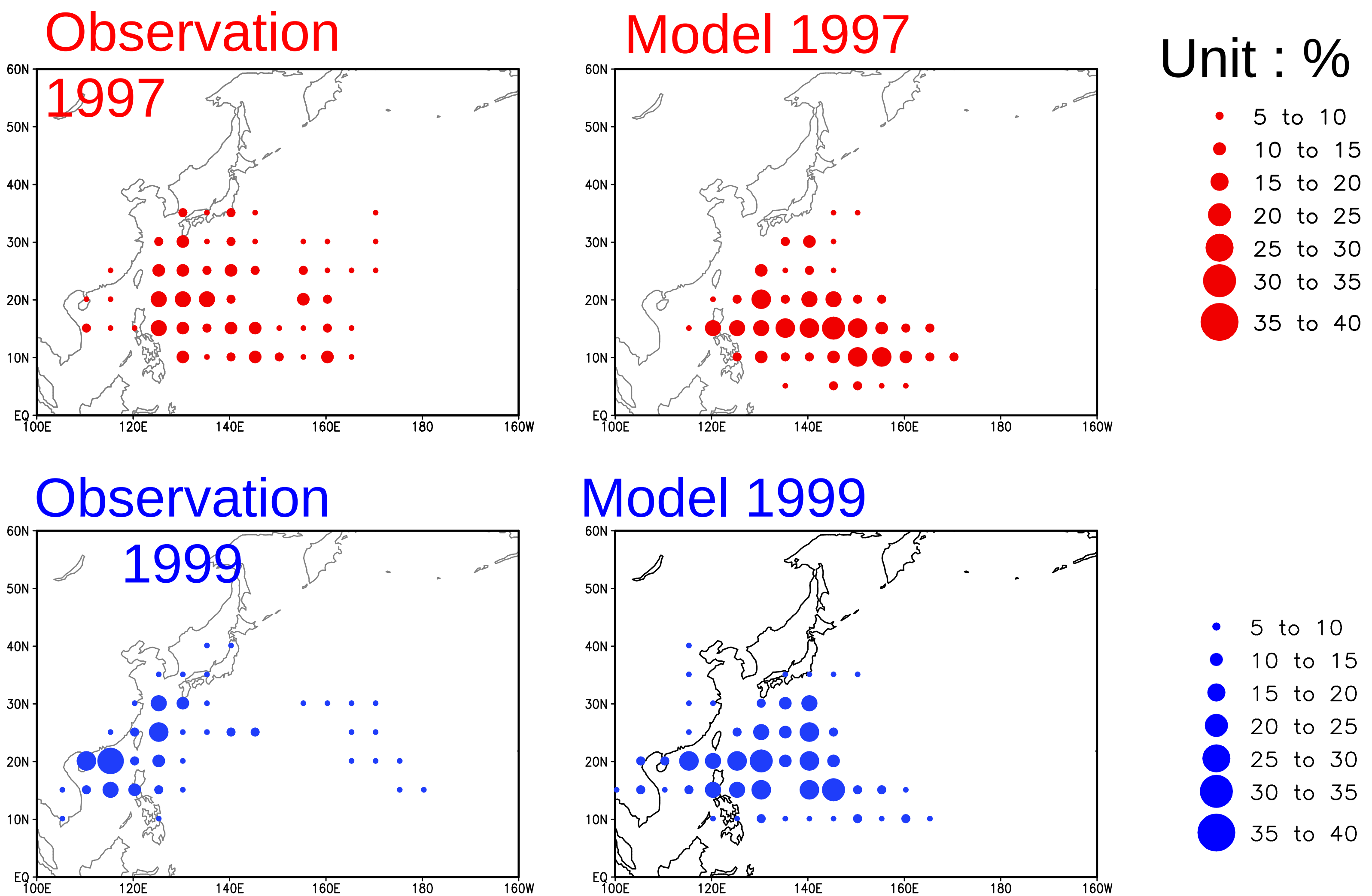
1999 mean location

	model	obs
Mean Lon.:	144.55	135.41
Mean Lat.:	16.17	18.46

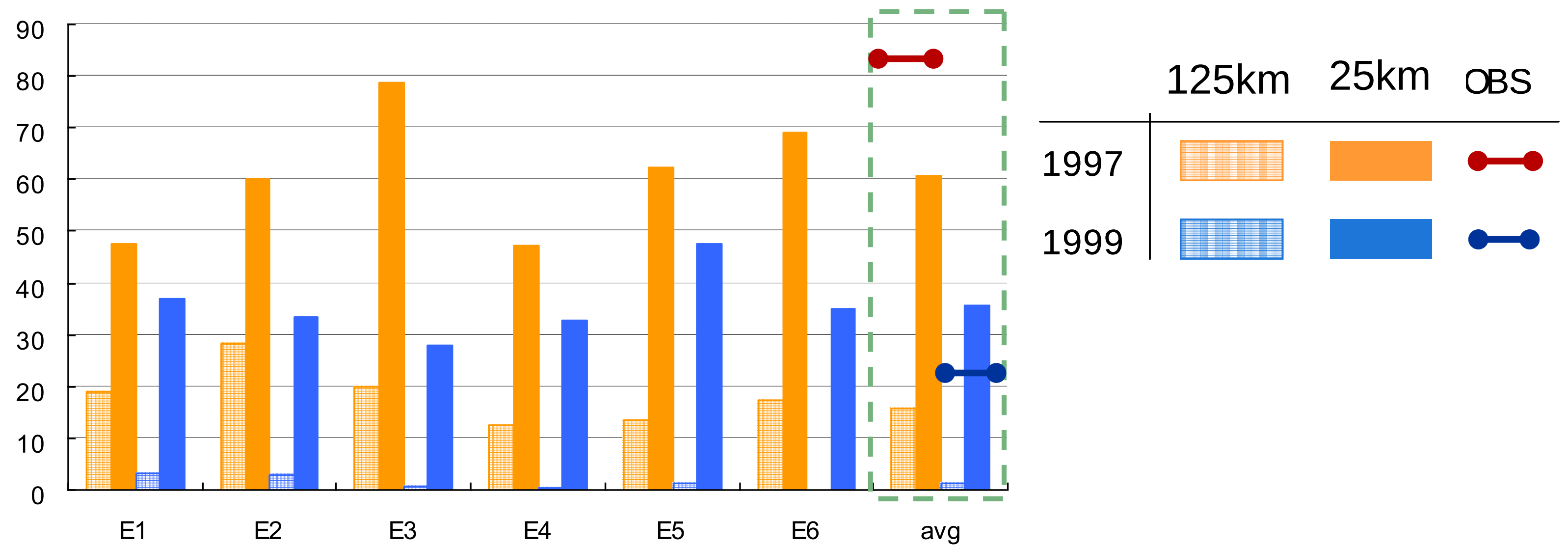
Mean location ● : model ● : obs.

The genesis locations of simulated TCs in 1997 and1999. Small gray closed dots are simulated TCs and small black closed dots are RSMC observation. The mean locations of model and observation are big gray and big black closed circles, respectively.

TC passage frequency



Accumulated Cyclone Energy



Accumulated cyclone energy (ACE,) of simulated tropical cyclones in 1997 and 1999 with 25km and 125km resolutions. All ensembles are represented and last bars at the end of right which are enclosed by long-dashed green square are mean values. Lines with closed circles at both edges are the ACE of the observation.

Project for coordinated high resolution model simulations of observed tropical storm activity

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Assessing sensitivity to model resolution, physics

Physical Mechanisms

Understanding mechanisms that impact tropical storms: focus on SST and MJO

Mechanisms

- Impact of SSTs on tropical storms
  - Impacts of different ocean basins (frequency, tracks, intensity)
  - Sensitivity to details of SST (resolution, climatology, etc)
  - Dynamical (vertical shear) versus thermodynamical (stability) changes
  - Links to changes in AEJ, AEWs, shifts in ITCZ, etc.
  - Noise levels (intra-ensemble spread)
  - Compare with “coarse” (~ 2°) resolution runs

- Impact of MJO on tropical storms
  - Assess quality of MJO simulations (USCLIVAR MJO WG metrics)
  - Direct impacts on shear, large scale convergence, etc.
  - Indirect impacts associated with changes in AEJ, AEWs, etc.

Impact of SST – Build on USCLIVAR WG Project on Drought*

- All models were forced with the same set of idealized SSTs including a control with climatological SST, and AMIP simulations
- Involved several AGCMs and one coupled model run at ~ 2° horizontal resolution
  - NASA GMAO/NSIPP-1, GFDL/AM2.1, NCAR/CAM3.5, NCEP, Lamont/CCM3, COLA/Univ. Miami CCSM

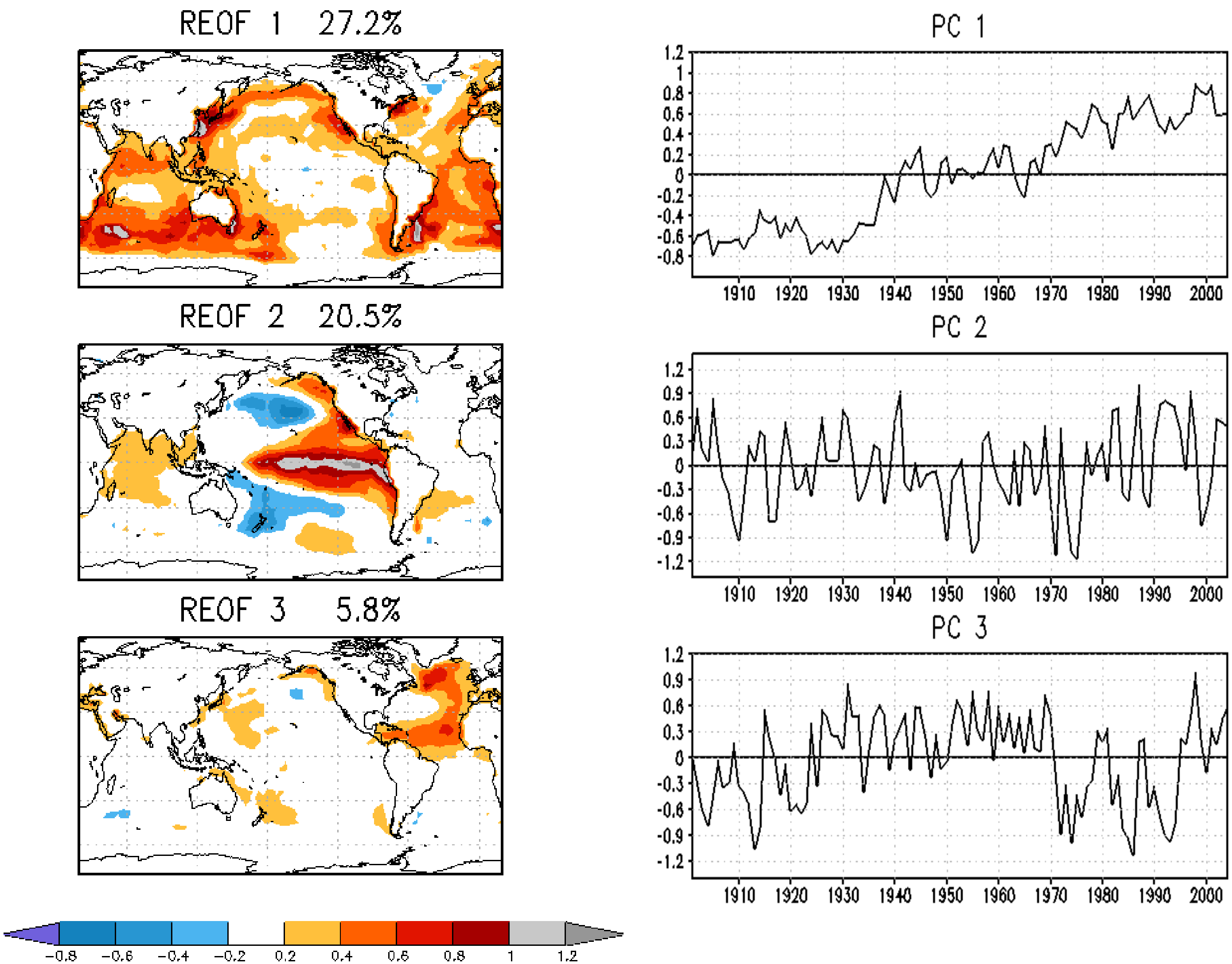
*Schubert et al. 2009: A USCLIVAR Project to Assess and Compare the Responses of Global Climate Models to Drought-Related SST Forcing Patterns: Overview and Results. To appear in JCLIM

Leading EOFs and Time series (annual mean SST - 1901-2004)

Linear Trend Pattern (LT)

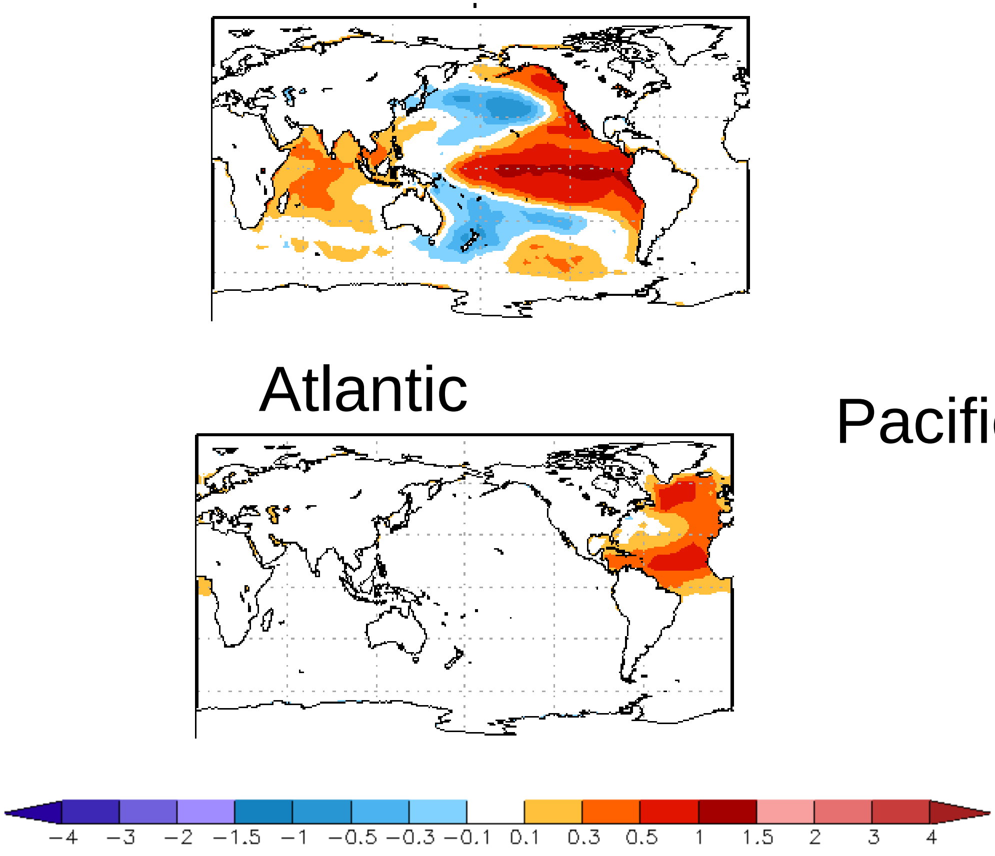
Pacific Pattern (Pac)

Atlantic Pattern (Atl)



Idealized Experiments

Pacific



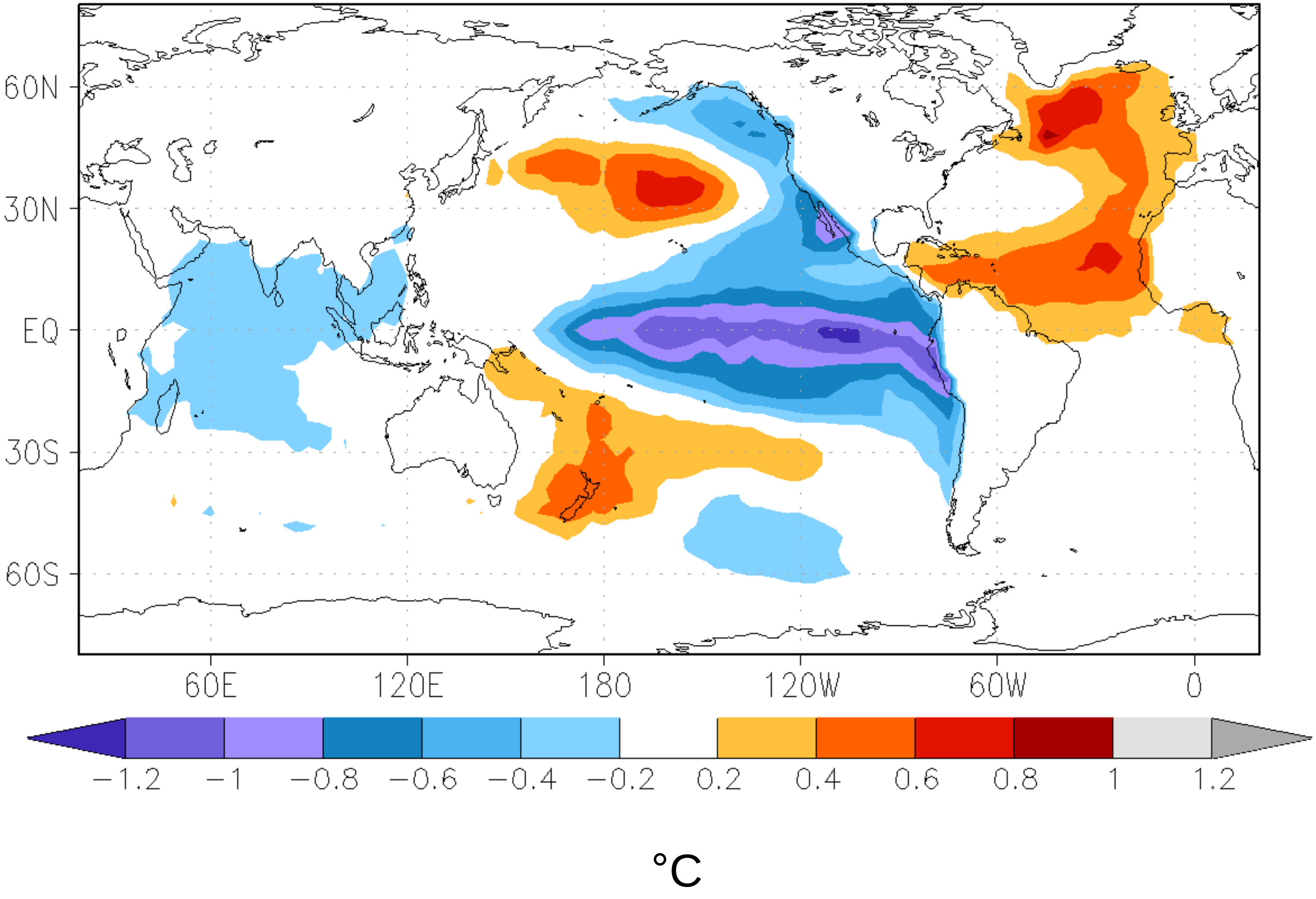
SST Forcing patterns
(warm phase)

Atlantic

Pacific

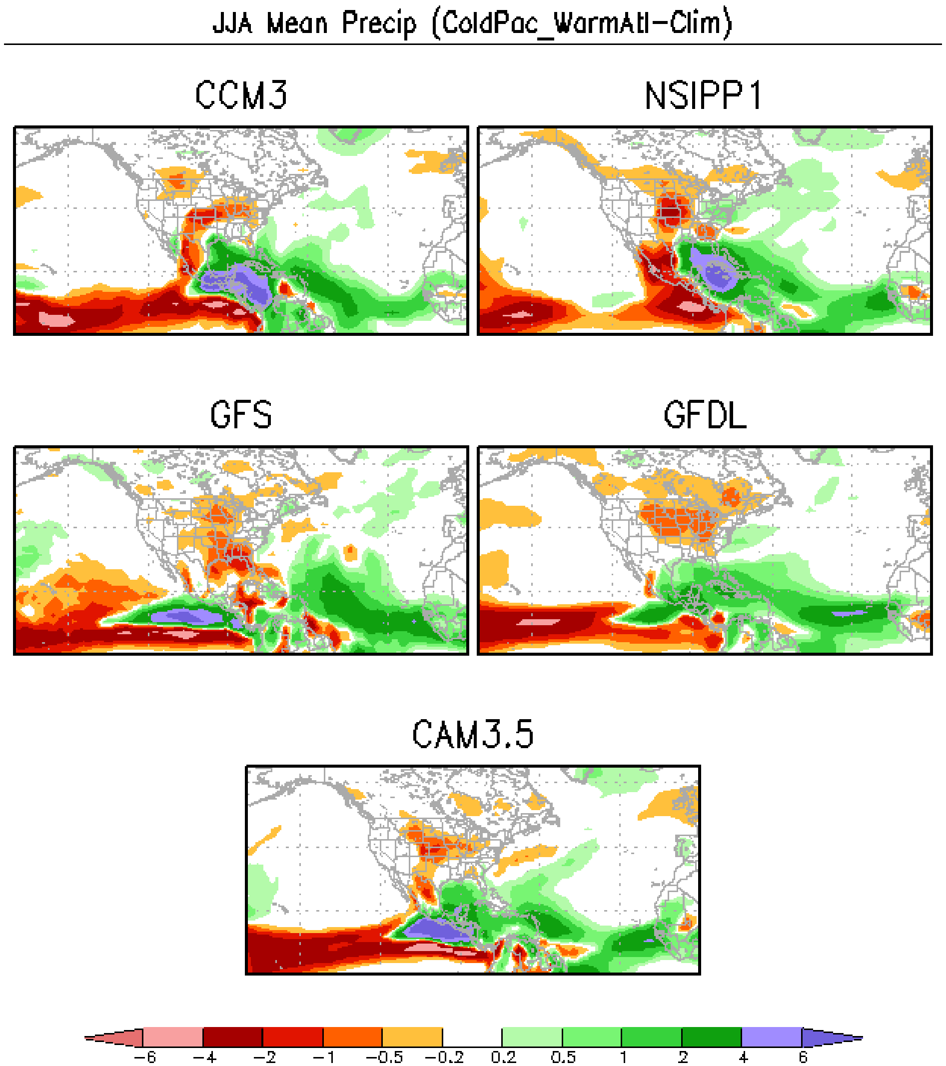
	warm	neutral	cold
warm	ww	wn	cw
neutral	nw		nc
cold	wc	cn	cc

Optimal SST Forcing for Drought in US
(what about tropical storms?)

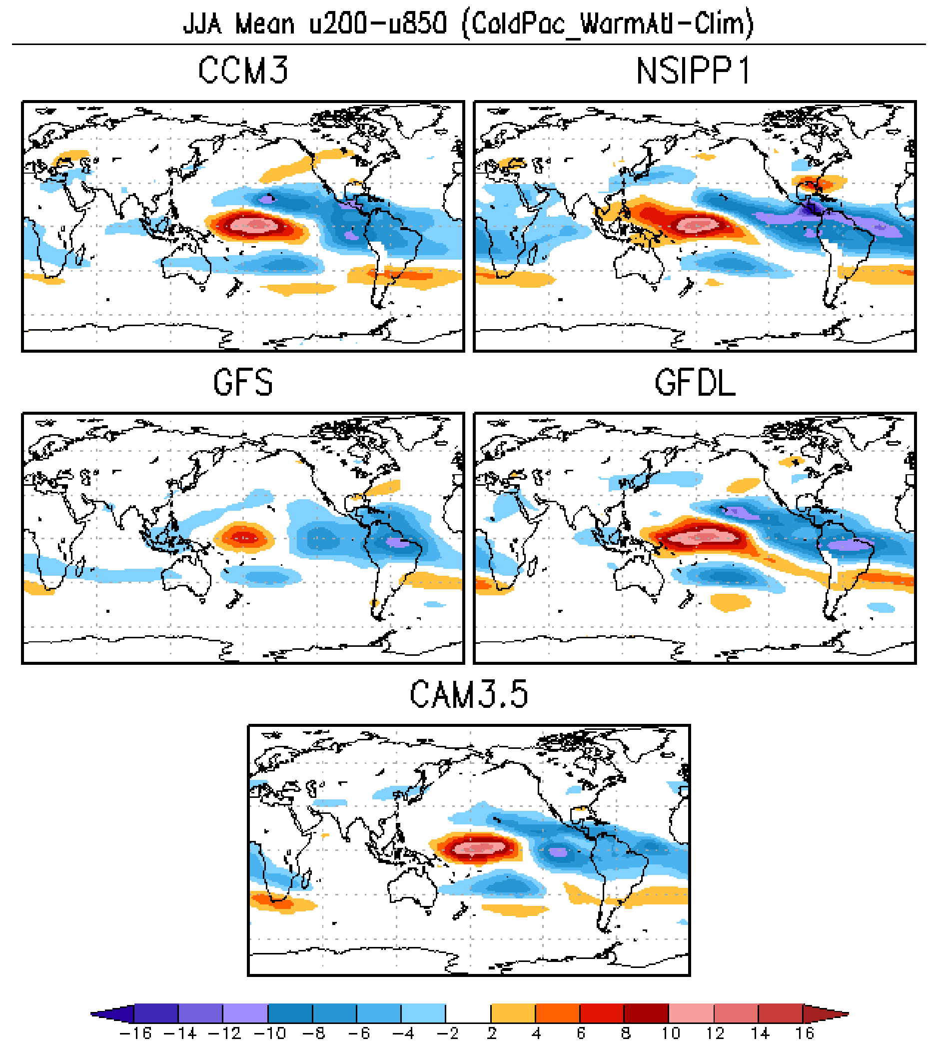


JJA: Cold Pacific and Warm Atlantic

Precipitation

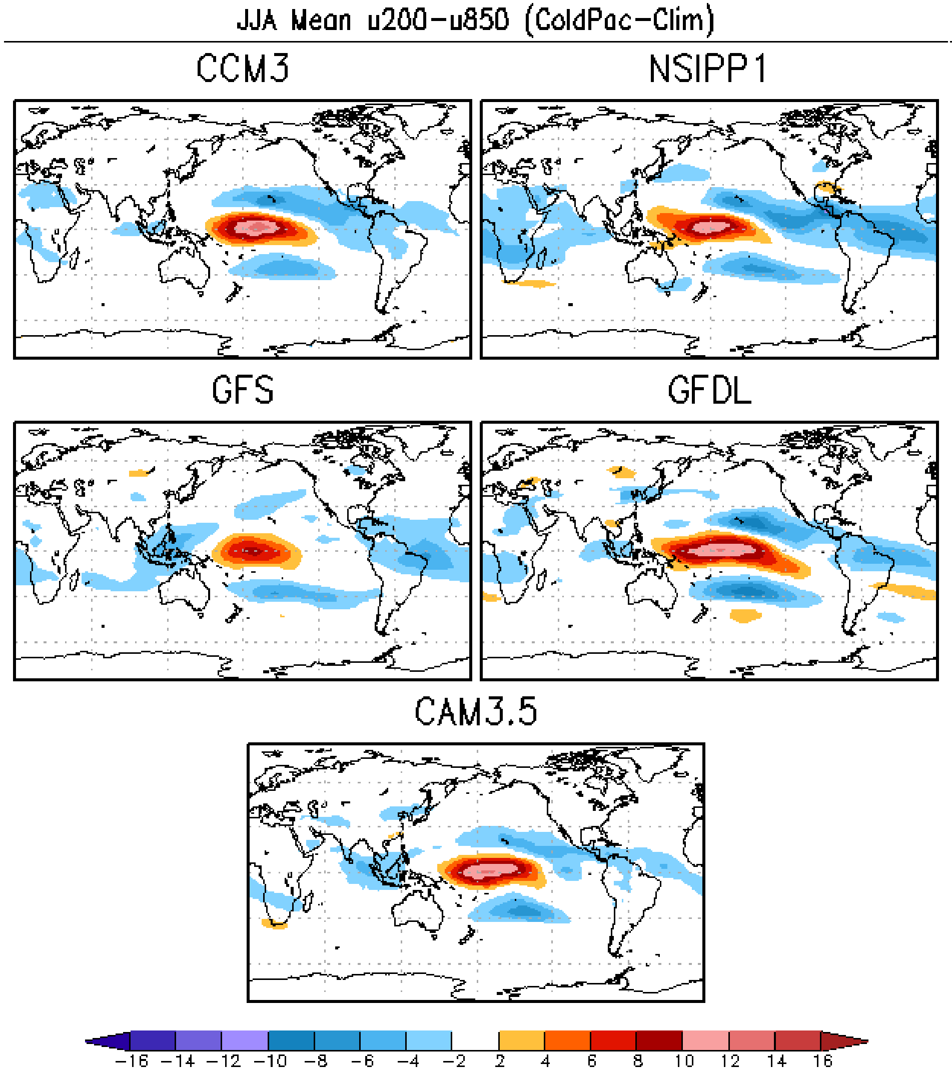


U200mb-U850mb

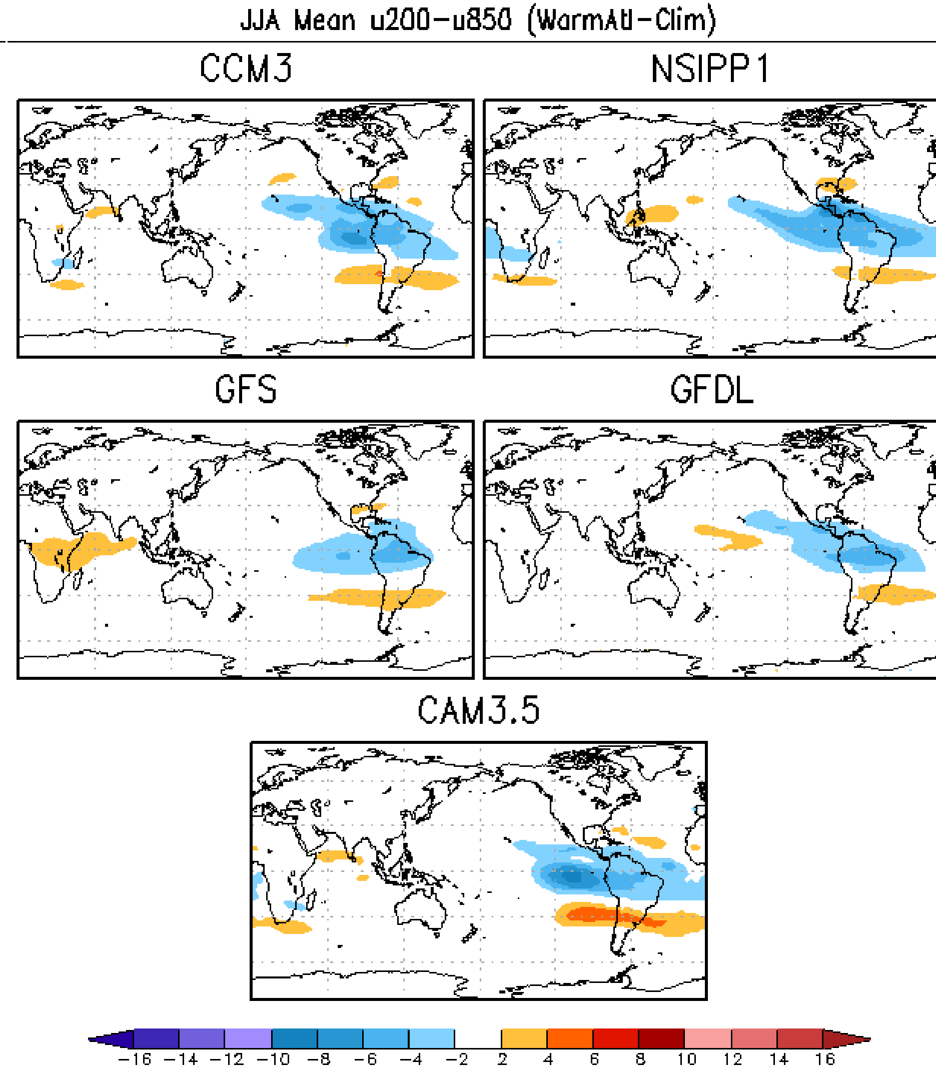


U200mb-U850mb

JJA: Cold Pacific

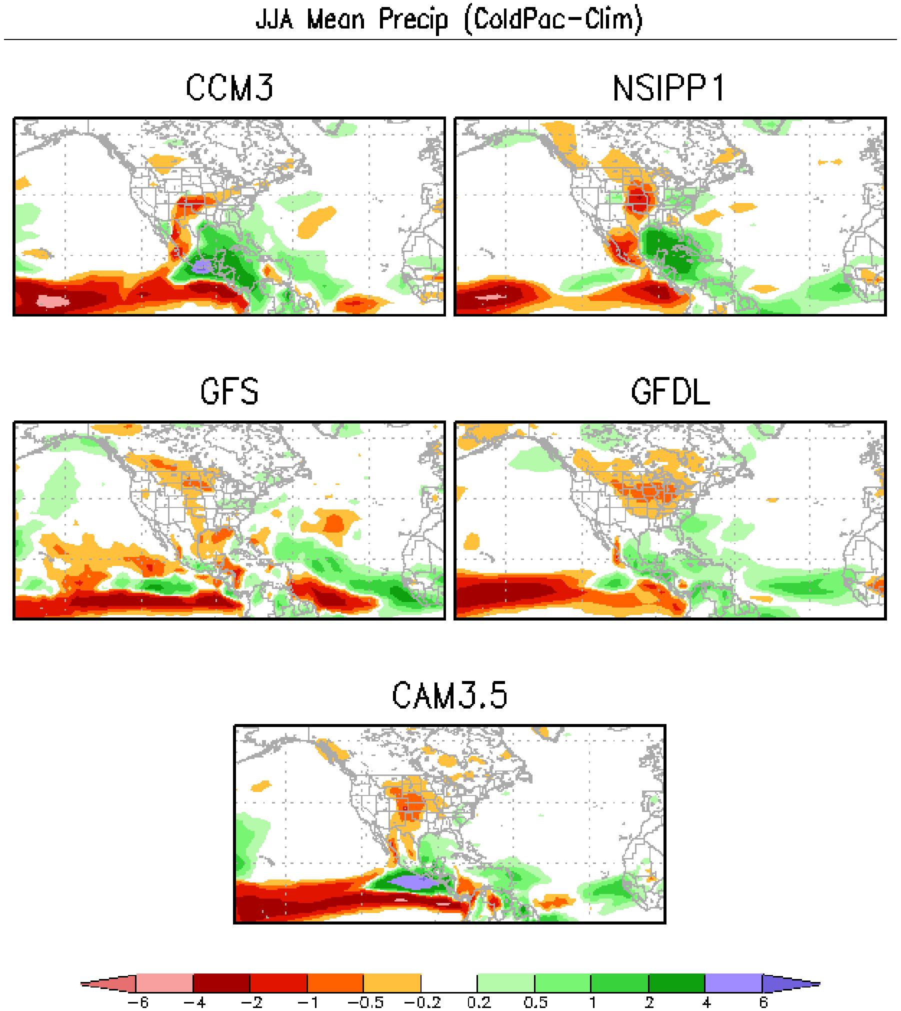


JJA: Warm Atlantic

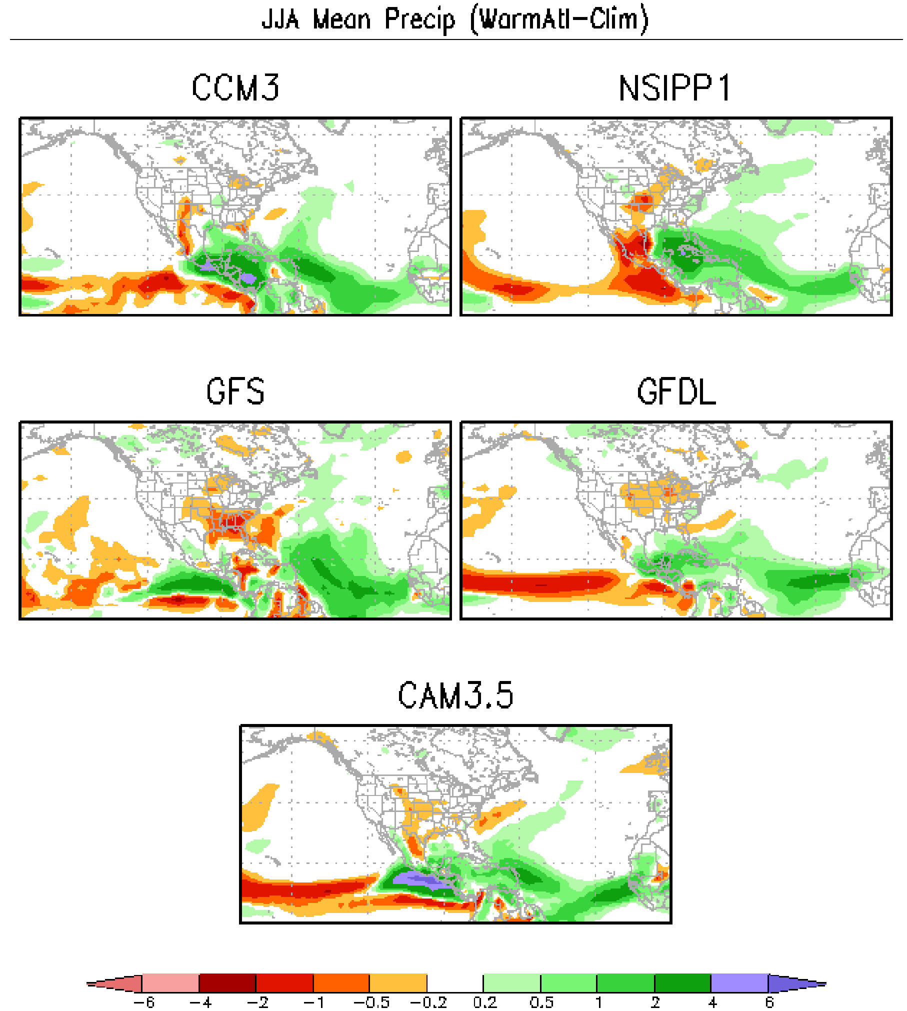


Precipitation

JJA: Cold Pacific

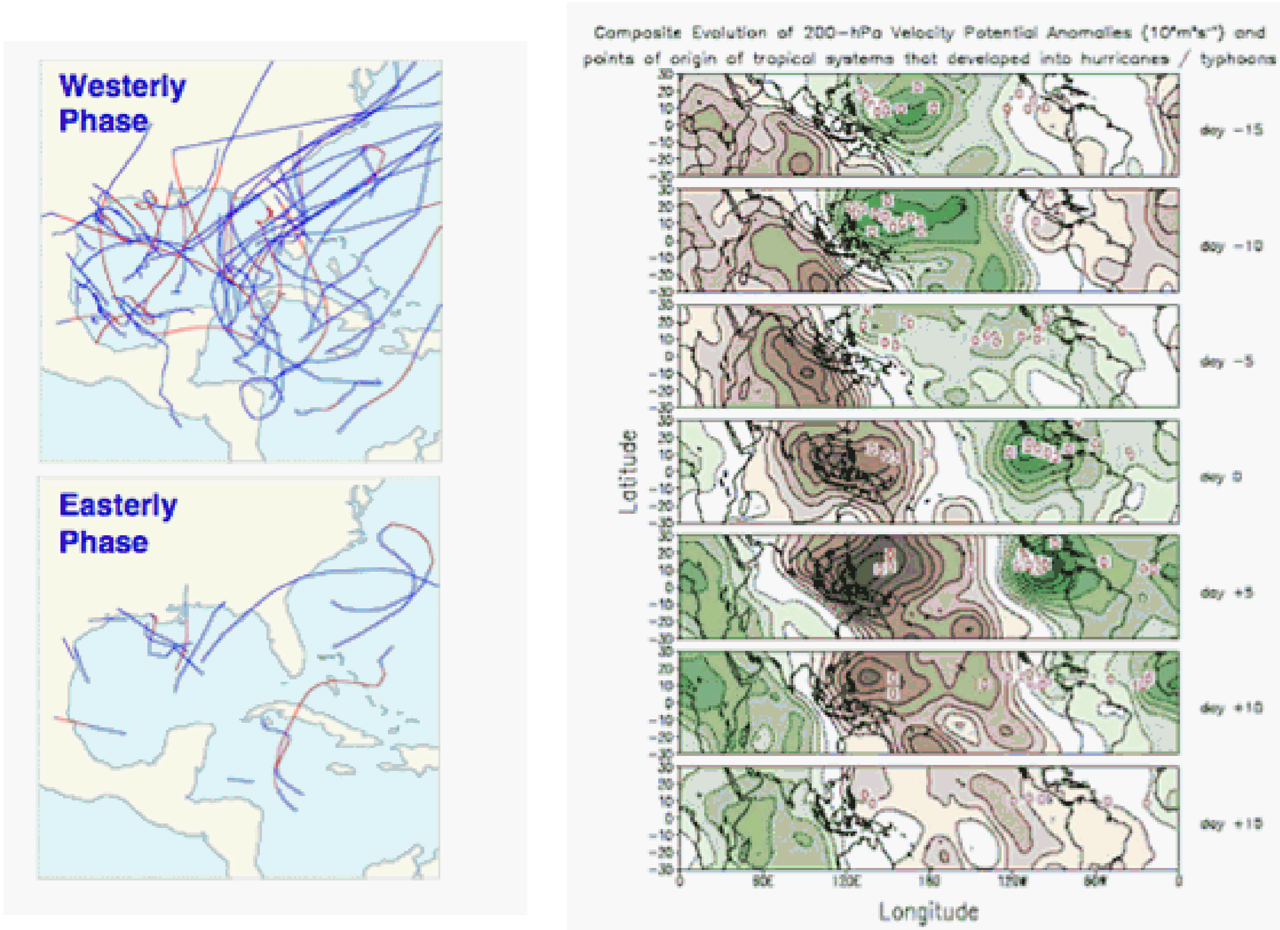


JJA: Warm Atlantic



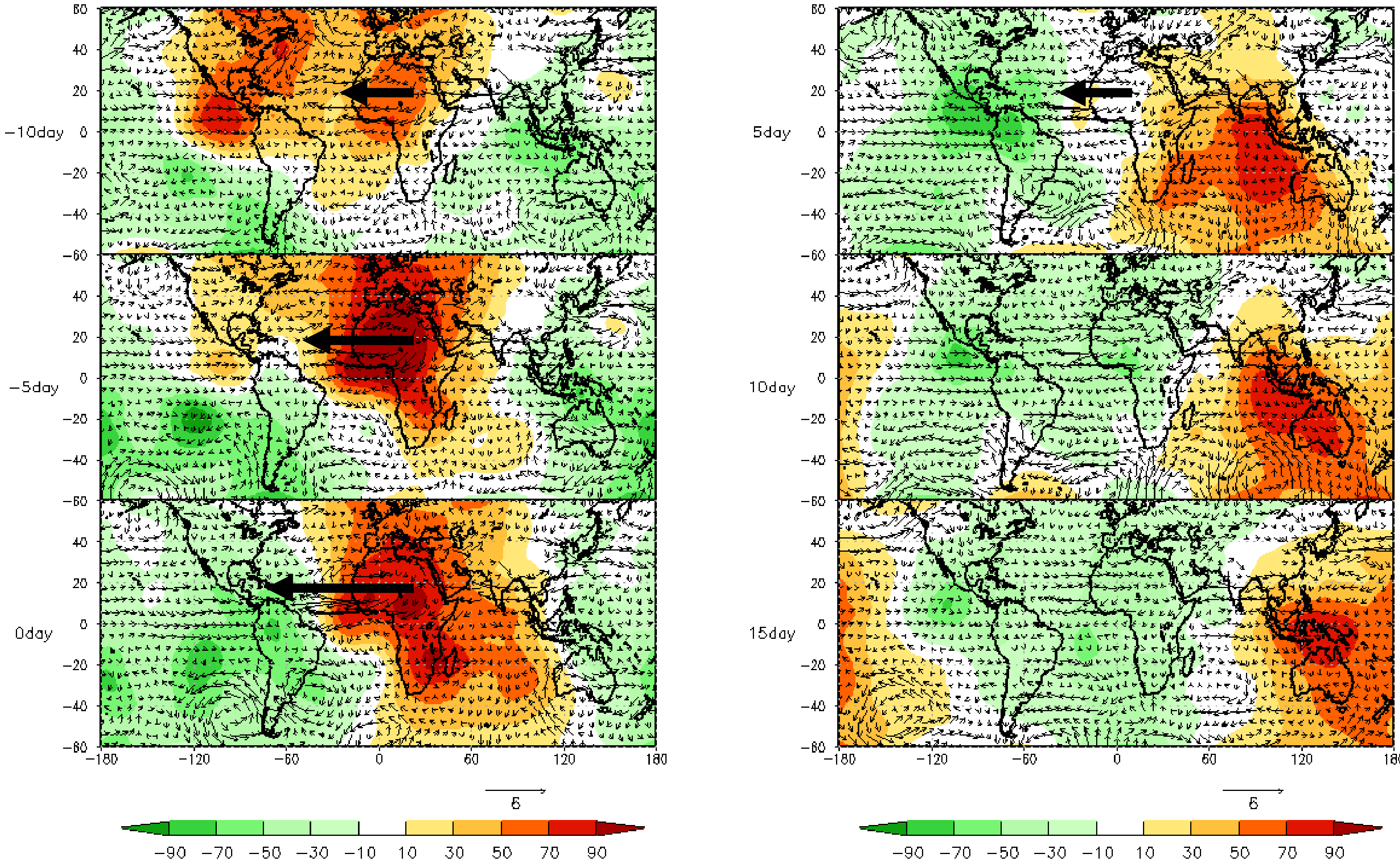
MJO Impacts

- MJO characteristics evaluated using USCLIVAR MJO working group metrics
- Tropical storm composites based on MJO
- Case studies as outlined earlier
  - Need atmospheric initialization capability
- Perhaps something more idealized?



a) The impact of the phase of the MJO on hurricane development in the Gulf of Mexico and western Caribbean - from Maloney and Hartman (2001) and as posted on the USCLIVAR MJO webpage- http://www.usclivar.org/mjo.php, b) Velocity potential composites for different phases of the MJO cycle with hurricane/typhoon origin locations. Green shading indicates upper level divergence and brow shading indicates upper level convergence. Open circles indicate hurricane/typhoon origin centers (Higgins and Shi 2001).

Link Between MJO and AEJ



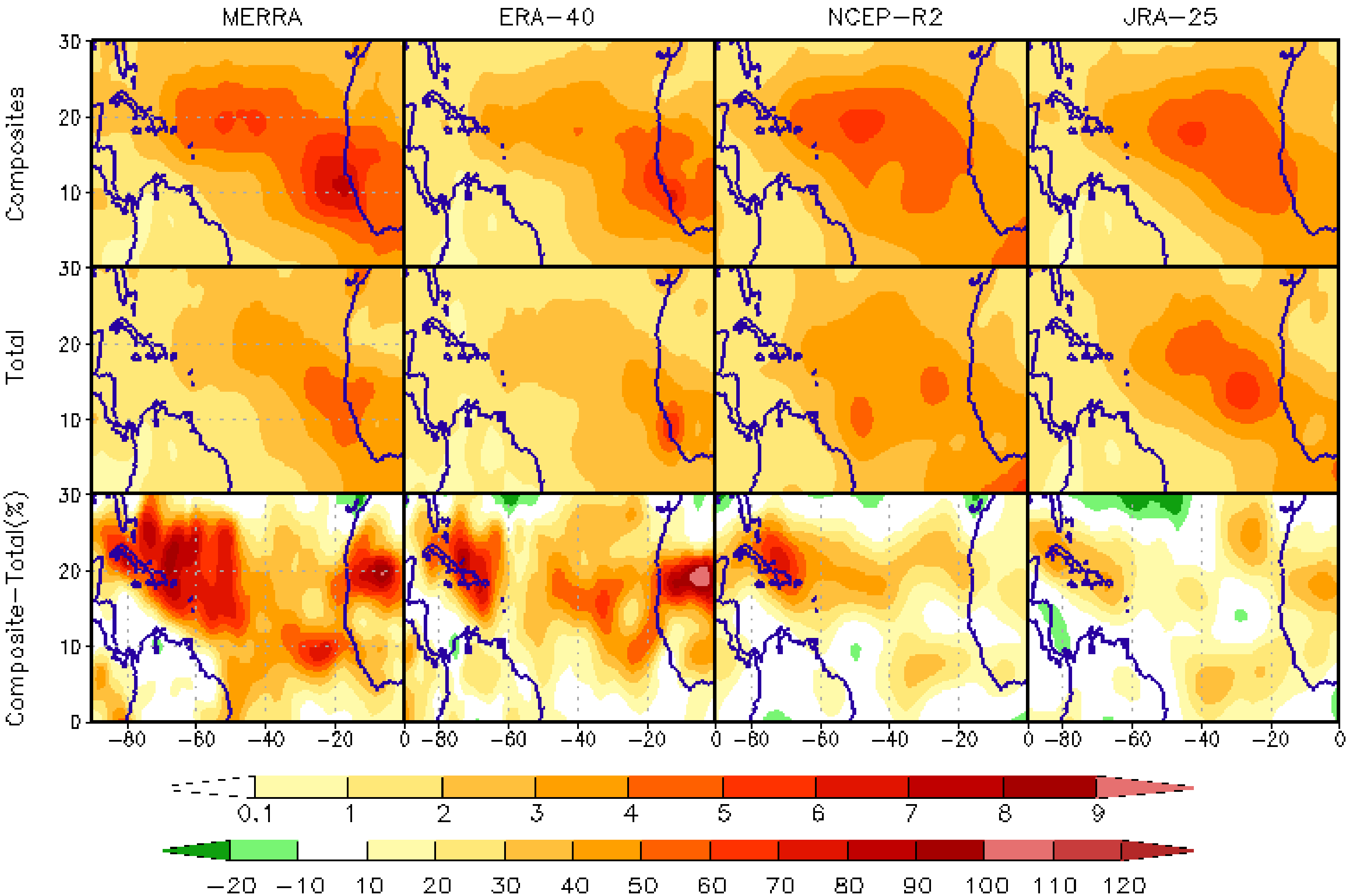
Man Li Wu (NASA/GMAO)

Impact of AEJ on Easterly Wave Activity

Strong Jet Composite (v'2)

Average (v'2)

Percent Change

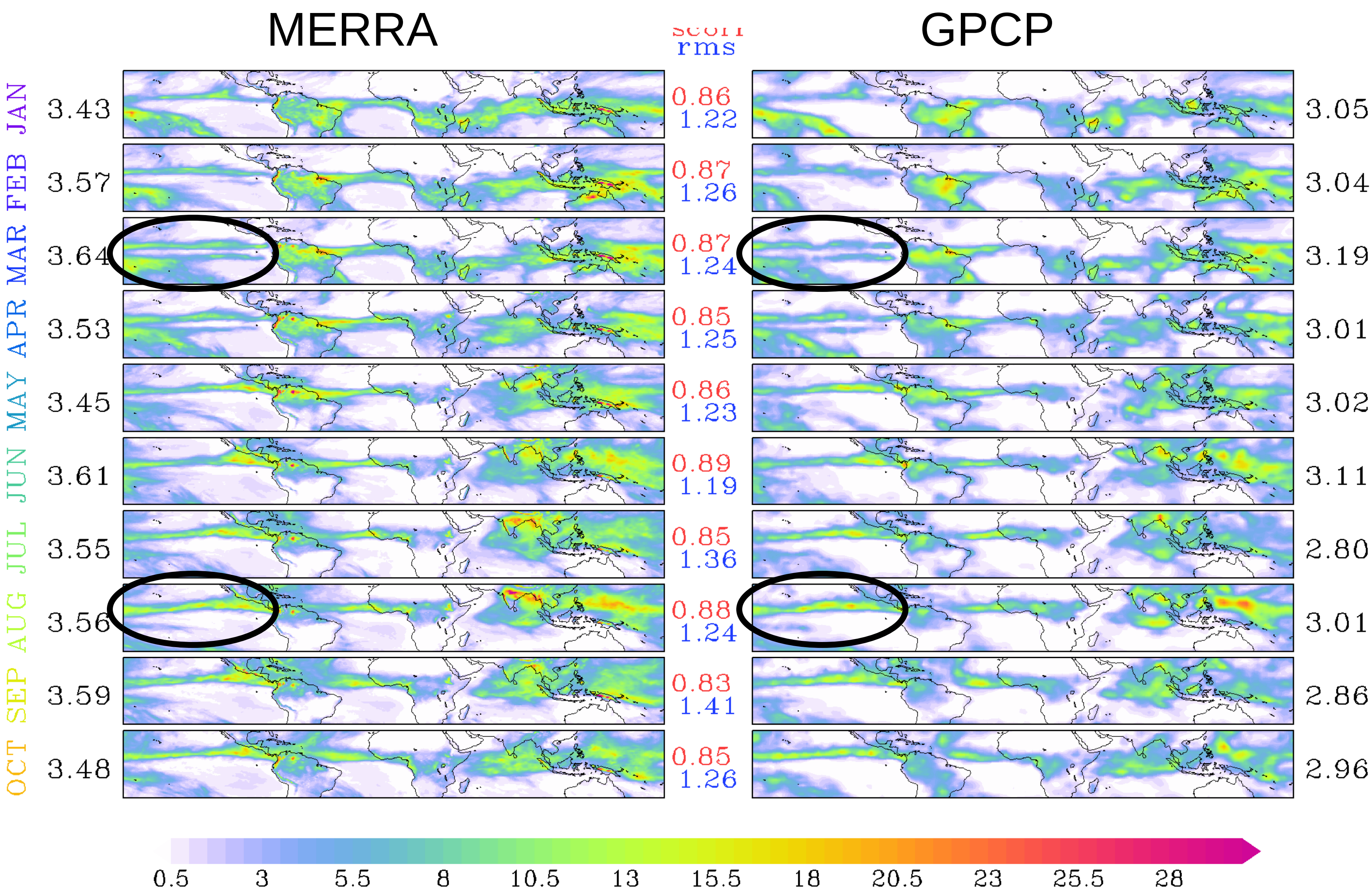


Man Li Wu (NASA/GMAO)

To What Extent Can We Using New High Resolution Reanalysis Products to Help In Validation/Understanding?

- NOAA CFSRR (T382 L64)
- NASA/GMAO MERRA (0.5° L72)
- ERA-Interim (T255 L91)
- JRA-55 (T319 L60)

2004 Tropical Precipitation



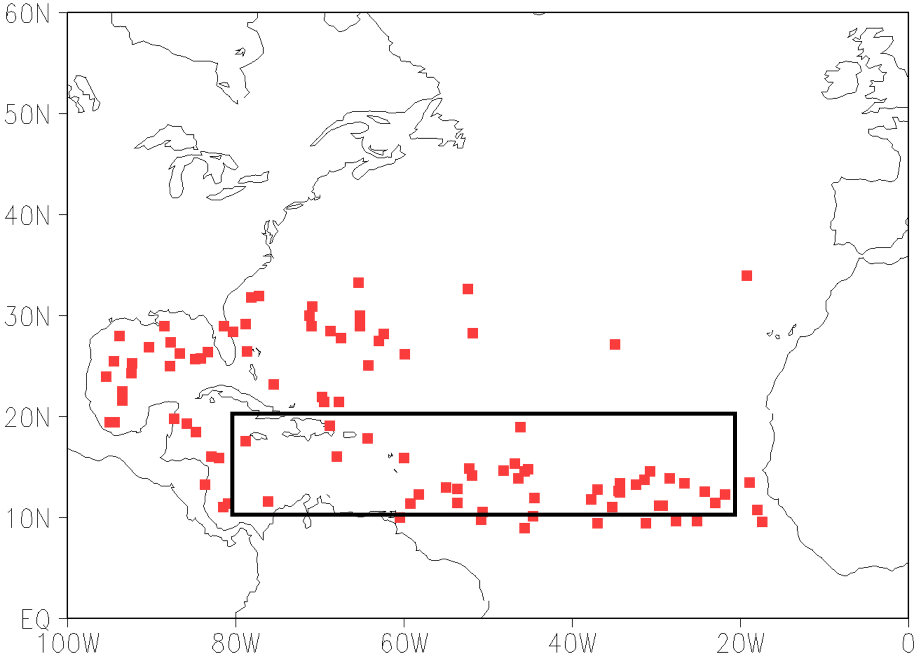
Tropical Storms in MERRA

(Myong-In Lee)

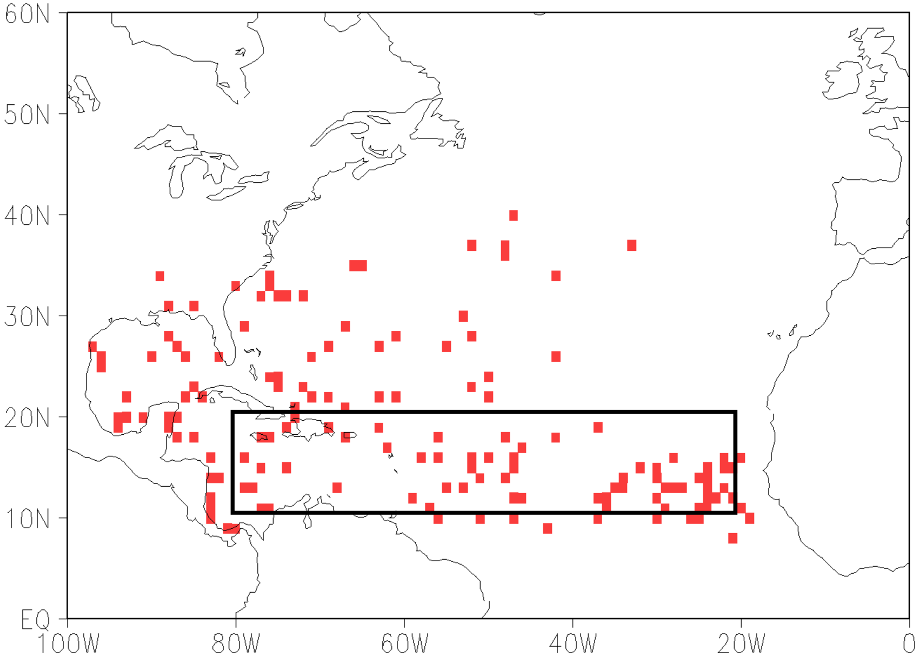
- Tracking tropical storms for the recent years 1998-2005
- *Applied to 3 hourly, 1-degree products (condensed from 0.5 degree native grids)*
- NCEP/CPC tracking version (Lindsey Williams/Jae Schemm)
- Tracking tools based on the method of Camargo and Zebiak (2002); basin-dependent thresholds of vorticity@850, 10-m wind, and vertically integrated temperature anomaly

Tropical Storm Origins
(August-October, 1998-2005)

Observations (Best Track)

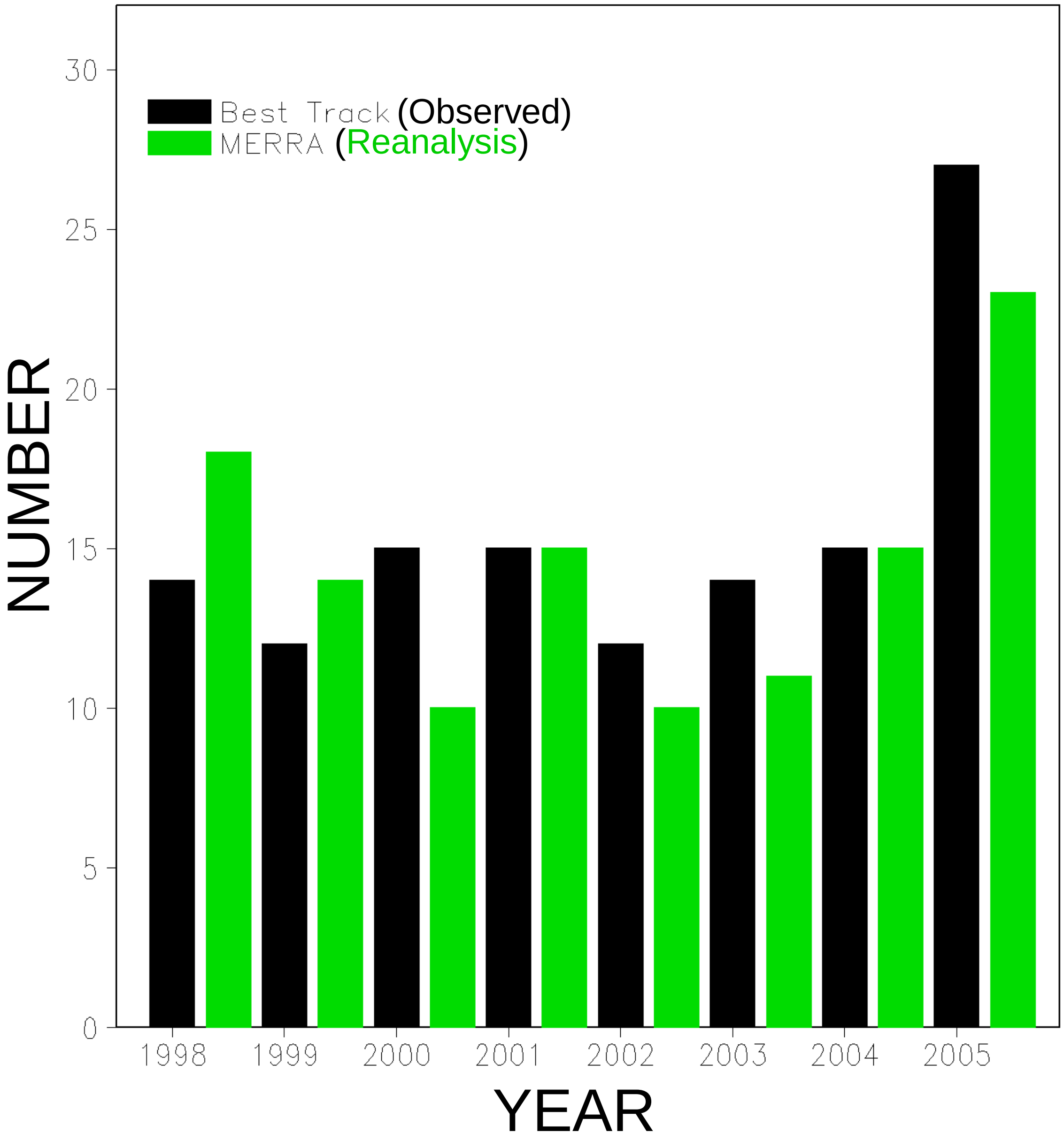


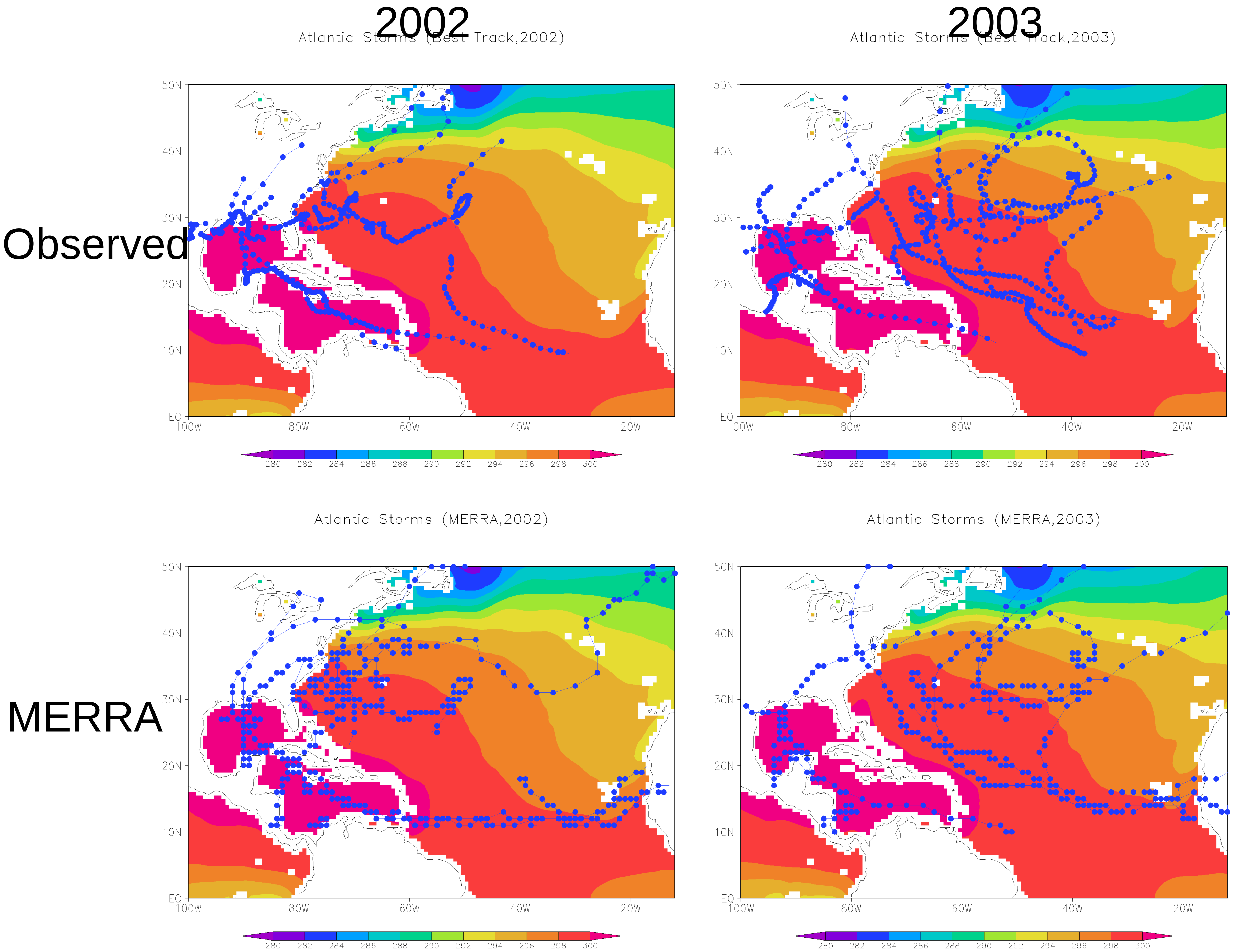
MERRA Reanalysis



Box: Main Development Region (MDR)

Number of Tropical Storms in Atlantic (March-November)



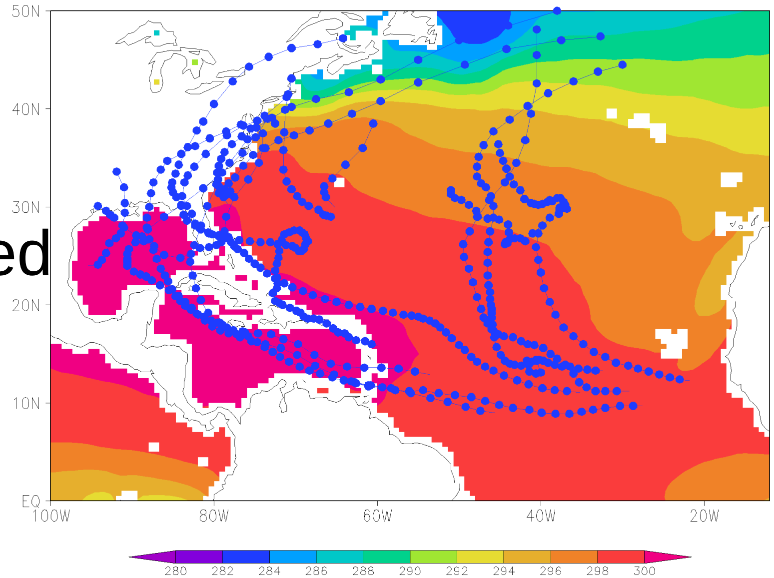

2002
2003
Observed
MERRA
Atlantic Storms (Best Track,2002)
Atlantic Storms (Best Track,2003)
Atlantic Storms (MERRA,2002)
Atlantic Storms (MERRA,2003)
50N
40N
30N
20N
10N
EQ
100W
80W
60W
40W
20W
280
282
284
286
288
290
292
294
296
298
300

2004

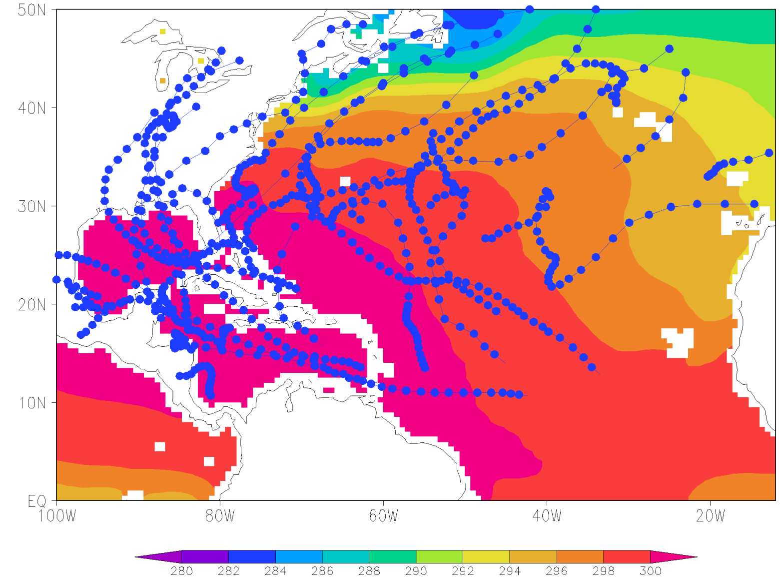
2005

Atlantic Storms (Best Track,2004)

Observed

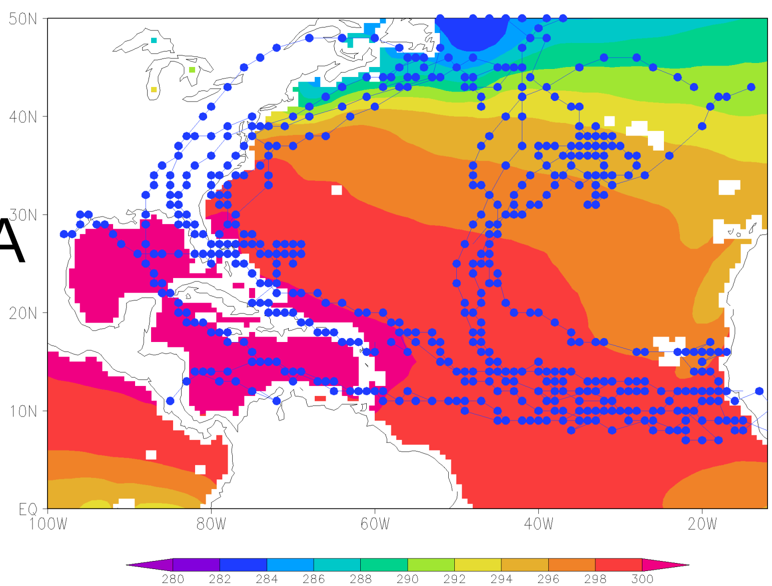


Atlantic Storms (Best Track,2005)

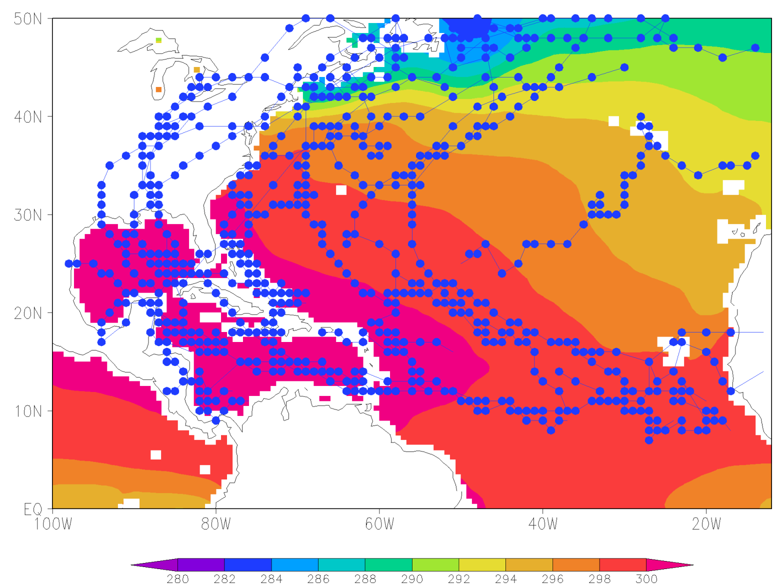


MERRA

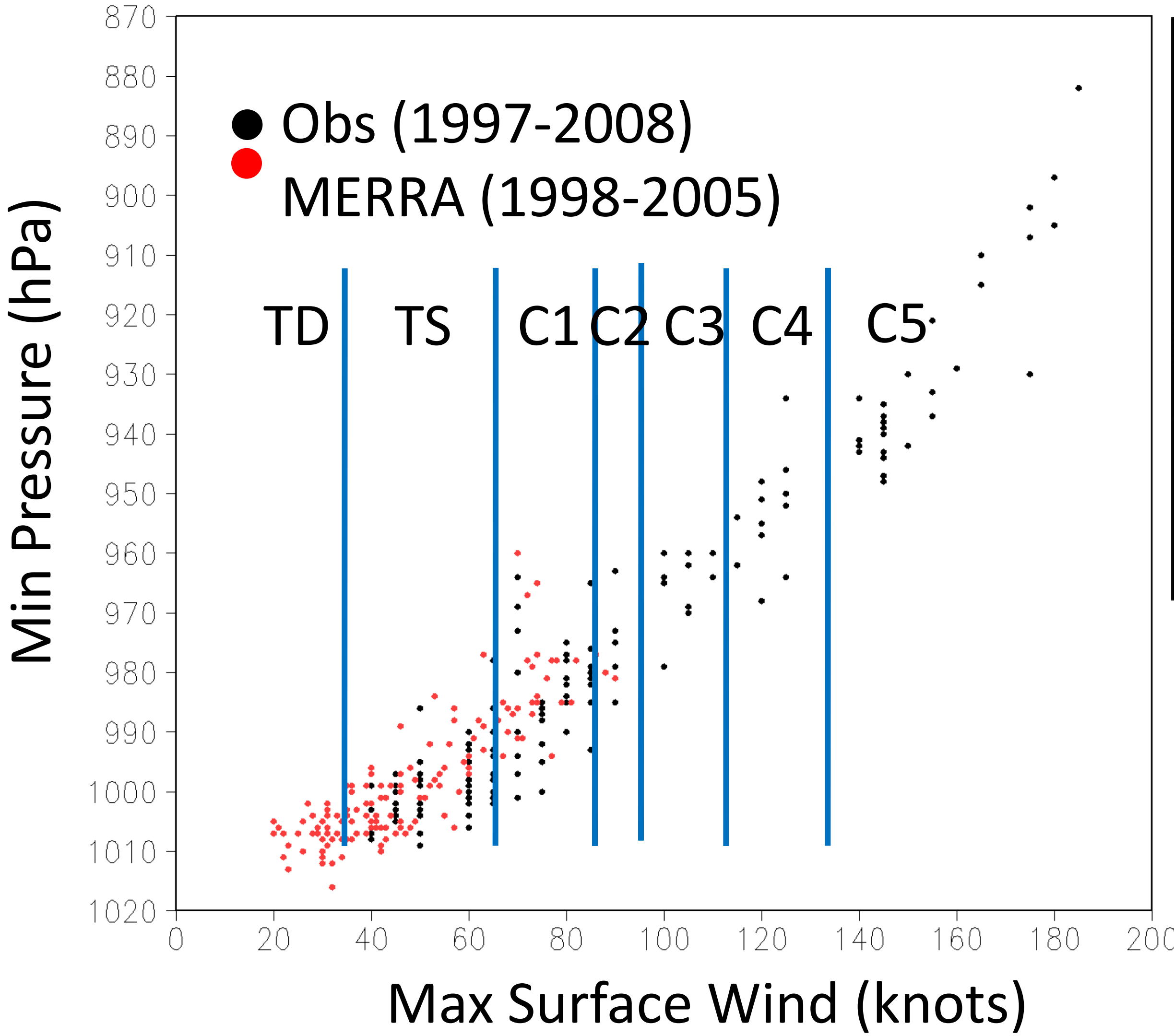
Atlantic Storms (MERRA,2004)



Atlantic Storms (MERRA,2005)



Tropical Storm Maximum Intensity (1998-2005)



Saffir-Simpson Hurricane Scale		
Category	Wind Speed	
	mph	knots
5	≥156	≥135
4	131-155	114-134
3	111-130	96-113
2	96-110	84-95
1	74-95	65-83
Non-Hurricane Classifications		
Tropical Storm	39-73	34-64
Tropical Depression	0-38	0-33

Comments

- Dependence on tracking tool?
- Impact of resolution – should use native resolution (0.5° in case of MERRA, also keep many quantities hourly)
- Dependence on assimilating model – need comparative studies
- Analysis increments can provide insights into model deficiencies – e.g., too strong sfc drag

Expected Outcomes of Collaborative Efforts

- An assessment of the ability of current climate models, when run at high resolution, to simulate tropical storms and changes in tropical storm activity (model dependence, basic noise levels/strength of SST and MJO)
- Improved understanding of the physical mechanisms controlling major changes in tropical storm activity on subseasonal, seasonal and longer time scales (role of SST, role of MJO/ISO)
- An assessment of sensitivity of the results to model resolution and physics and guidance on how to improve the models
- An assessment of the predictability of major changes in tropical storm activity (linked to prediction of MJO and S-I ocean variability)

Thursday and Friday Discussion

- Summarize existing simulations and discuss relevant activities (YOTC, TCMIP, IPCC, APCC, etc)
- Discuss possible coordinated mechanistic experiments: e.g., idealized SST
- Discuss possible coordinated model sensitivity experiments
- Common tropical storm metrics, diagnostics, tracking tools, output
- Data sharing